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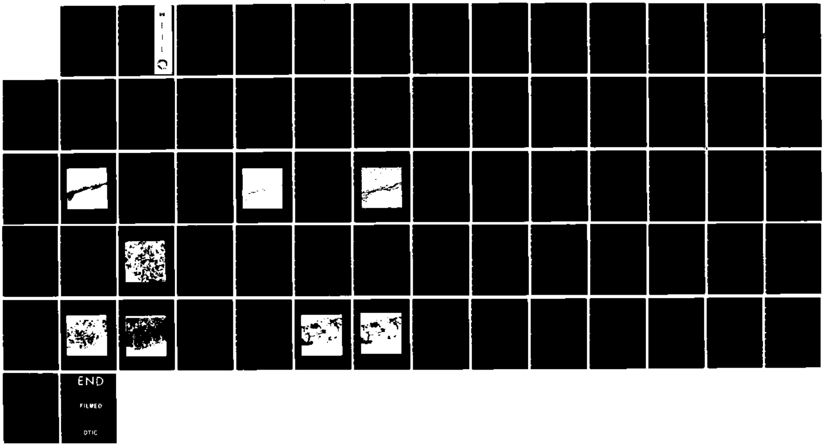

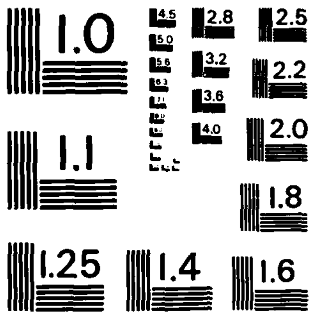

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Interactive digital image processing for terrain data extraction, phase 5

Howard Heydt
Vijay Karkhanis
Christopher Peterson

General Electric Company
Space Systems Division
4701 Forbes Blvd.
Lanham, Maryland 20706

September 1984

Prepared for

U.S. ARMY CORPS OF ENGINEERS
ENGINEER TOPOGRAPHIC LABORATORIES
FORT BELVOIR, VIRGINIA 22060-5546

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Some techniques were investigated for extracting terrain surface roughness data from digital aerial imagery. Measurement of tonal changes in the imagery is one feasible approach. A digital image data base was assembled containing 10 image planes, 4096 x 4096 pixels/plane, 8 bits/pixel. The planes contain Landsat Thematic Mapper image data, four digitized aerial photos which were rectified, registered to the Thematic Mapper image and mosaicked, and digitized aerial radar imagery, all for the same scene. From the digital photomosaic, open water and forested areas were extracted using a gray level-texture classification

SUMMARY

The overall Terrain Data Extraction Study is concerned with the development of techniques for the extraction of terrain features from digital aerial imagery, and for related techniques necessary to implement the extraction process with map-sized images. Typical features to be extracted are vegetation boundaries, forest canopy closure, and tree stem spacing in forested areas. Extracted data pertaining to features such as these are an input to decision-making processes associated with military operations such as cross-country movement. Phase 5 of the study, reported here, included three tasks: investigation of techniques for the extraction of surface configuration data; assembly of a multi-plane image data base; and extraction of water and forested areas from the data base imagery.

The surface configuration investigation focused on techniques to extract some of the data elements comprising the Surface Roughness Index (SRI). Specifically, the elements studied were the frequency of occurrence of point and linear obstacles and of tonal changes in the imagery. Useful results were obtained for the extraction of tonal change data, and some special case results were obtained for the frequency of occurrence of obstacles. The investigation has been very limited, however. The current techniques need to be studied more thoroughly, and additional techniques need to be devised and evaluated.

A major task in Phase 5 has been the assembly of a multi-plane image data base containing digitized, scaled and registered image data, including an aerial photomosaic, radar imagery and Landsat Thematic Mapper imagery. The data base is structured for 10 image planes of 4096 x 4096 pixels, with 8 bits/pixel/plane. This approaches "map-sized" images. A mosaic of four digitized overlapping aerial photos comprises one plane in the data base. Producing the mosaic was a major effort in itself, involving rectification, scaling, rotation, merging and radiometric balancing. The Thematic Mapper image was the reference and source of control point information. Algorithms

and software developed in Phase 4 of the study were used in the mosaicking process.

The third task in Phase 5 involved the extraction of open water and forested areas from the data base imagery, using techniques developed in a prior phase for smaller scenes. A texture image was derived from the digital photomosaic, and these two images were then analyzed jointly to produce binary maps (thematic maps) for water and forest areas. These thematic maps have been stored in bit planes within the 8-bit image planes of the data base. Using algorithms and software developed in Phase 4, theme contouring was performed for 512 x 512 - pixel images from the thematic maps in the data base. The contour data were converted to vector format and recorded on magnetic tape in the Standard Interface Format.

A map-sized hard copy image (photographic print) of every plane in the data base has been produced. These include the input images, the thematic maps (results), and intermediate images (e.g., photomosaic texture).

PREFACE

This document has been prepared under contract DAAK70-79-C-0153 for the U.S. Army Engineer Topographic Laboratories, Fort Belvoir, Virginia 22060-5546, by the General Electric Company, Space Systems Division, Lanham, Maryland 20706. The Contracting Officer's Representative was Mr. Randall S. Karalus.

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INTERACTIVE DIGITAL IMAGE PROCESSING FOR TERRAIN DATA EXTRACTION, PHASE 5

1. INTRODUCTION

This report documents the results of Phase 5 of the Terrain Data Extraction Study. Phase 5 effort was performed during the period November 1983 - September 1984. The overall study addresses the problem of extraction, from digital aerial imagery, of terrain features essential for decisions associated with military operations such as cross-country movement. Also addressed in the study is the generation of certain terrain analysis products (e.g., factor overlays or maps) necessary for the decision-making associated with these military operations. Beginning in September 1979, the first three phases of the study focused primarily on the extraction, from panchromatic aerial photography, of vegetation and other land-cover boundaries, and on the extraction of forest features such as canopy closure and stem spacing. See the Phase 1 report ETL-0241, November 1980 for a more complete description.

During Phase 4 the groundwork was laid for enabling the terrain data extraction techniques to become applicable to map-sized areas and to be automated to a useful level. Specifically, algorithms and software were developed for image scaling and mosaicking so that multiple adjacent frames of imagery can be accommodated. Further, algorithms and software were developed for automatically contouring digital thematic image data and converting this boundary information into vector format recorded on magnetic tape in Standard Interface Format.

In Phase 5, the phase reported here, one task pertained to investigating the extraction from digital aerial imagery of a new category of terrain features: Surface Configuration. Initially, this involved a review of the Procedural Guide for Surface Configuration to assess the procedures that best lend themselves to digital operations. Effort has been focused on extraction of some of the data elements comprising the Surface Roughness Index (SRI). Section 2 of this report describes this effort. The investigation was limited because of the high proportion of Phase 5 effort devoted to the Data Base

Assembly Task (see next paragraph). Additional investigation of Surface Configuration data extraction is highly desirable and should be pursued in the near future.

In a second Phase 5 task, a multi-plane image data base was assembled containing digitized, scaled and registered image data, including an aerial photomosaic, radar imagery and Landsat Thematic Mapper imagery. Assembling the multi-plane data base and achieving, in particular, an acceptable digital mosaic of four digitized, overlapping aerial photos, became the major effort in Phase 5. The steps involved, and results, are described in Section 3 of this report.

In a third Phase 5 task, using previously developed algorithms and techniques, forest and open water areas were extracted from the image data in the data base. The results are stored as binary themes (maps) in additional planes of the data base. From these, 512 x 512 pixel polygon (theme contour) images have been produced and recorded on tape in vector format. Larger (map-sized) polygon images are feasible and ultimately desired, but were not generated in this task because of the high proportion of Phase 5 effort devoted to assembling the data base. Section 4 of this report describes the extraction procedure for water and forest areas and the generation of the associated polygon images. Many other information extraction and data manipulation procedures for the data base imagery are possible and have potential. For example, good use can be made of the information contained in the multiple spectral bands of the Thematic Mapper image data. This can aid in land-cover mapping for the water and forest areas and for several other land-cover categories. But the Thematic Mapper image data, and also the radar image data, were not used for terrain feature extraction in this task. These image sources and techniques to extract information from them, should be investigated in the near future and appropriate software developed.

Map-sized hardcopy images produced from each plane in the data base are a requirement in Phase 5 and are a deliverable to USAETL in conjunction with the Technical Report.

The test bed for all technique development and evaluation in this program has been the General Electric Digital Image Analysis Laboratory (DIAL) facility in Lanham, Maryland.

2. EXTRACTION OF SURFACE CONFIGURATION DATA

2.1 Introduction

Surface configuration data are an important part of the information a military commander needs when decisions must be made concerning cross-country troop movements. In this section of the report an initial investigation is described pertaining to the application of interactive digital image processing to the extraction of surface configuration information from remote sensor imagery. The investigation has examined only a small portion of the problem because of limitations placed by a heavy emphasis in the Phase 5 effort on the multi-plane image data base tasks.

The USAETL Terrain Analysis Procedural Guide for Surface Configuration is the starting point for the investigation. As identified in the guide, Slope, Landform and Surface Roughness comprise Surface Configuration data. Surface irregularities and features that are too small for mapping are known as Surface Roughness, and attention was focused on these in the preliminary investigation. Specifically, a few elements were considered which are part of a Surface Roughness Index (SRI) for data extracted from aerial imagery: Tonal Changes; Point Obstacles; and Linear Obstacles. The Surface Roughness Index is defined in the procedural guide as:

$$SRI = 0.1\left(\frac{a+b}{2}\right)^2 + 0.1\sqrt{c} + 0.1d + 0.2e + f$$

$$\text{Where}\left.\begin{array}{l} a = \text{number of contour bends} \\ b = \text{number of gullies less than 3m. wide} \\ c = \text{number of point obstacles} \\ d = \text{number of fencerows} \\ e = \text{number of tonal changes} \\ f = \text{number of linear obstacles} \end{array}\right\}\text{per 1.2 km}$$

Most of the SRI elements involve elevation information in addition to plan view information. Point obstacles, for example, are described as small surface irregularities, greater than 1.5 meters high, such as boulders, pinnacles and sharp-pointed ridge crests. Unless stereo digital photographic imagery is used (it was not in this investigation), elevation information is available only by inference. Radar imagery, in conjunction with photographic imagery, could be useful in this situation, and these sources exist in the multi-plane image data base for the Elizabeth City, NC scene (see Section 3). The value of radar data, of course, is that it presents strong responses for surface edges and points, as would be the case for point and linear obstacles. However, no point obstacles appear to exist in the Elizabeth City scene, so the radar imagery approach could not be pursued. Tonal changes in the imagery can be examined digitally, however, and this was pursued in the investigation. A specialized approach to point and linear obstacles, exploiting shadow information, also was pursued.

2.2 Tonal Changes

As described in the procedural guide, the frequency of tonal changes in the photographic imagery is measured by counting and averaging the number of times the photography tone changes in value along specifically placed grid lines overlayed on the image*, using as a reference the ten density values in the Kodak Gray Scale referred to in the procedural guide. To perform these measurements digitally, corresponding gray level values are established for the digital data. Subscenes of 512 x 512 pixels extracted from the digital photomosaic in the data base were analyzed, and the radiometric range for such pixels is 0-255 digital levels. The ten digital values to be used when counting tonal changes were set as follows:

0	114	199
28	142	228
57	171	255
85		

* See section 2.2.3, Approach No. 3c. for a more explicit description of the procedure.

2.2.1 Tonal Change: Approach No. 1

In this approach, the digital image is level sliced in accordance with the ten equally spaced digital levels. A binary map (theme) is produced for each slice.

Each theme is then outlined, and all outlines composited. The result is shown for two subscenes in Figures 2.2.1.1 and 2.2.1.2. An appropriate grid could be overlayed on the outline image and image crossings of the grid counted. It is considered, however, that this approach, at least for these scenes and two-meter resolution, leads to an undesired level of detail. Much of the detail would not be recognizable at scales normally used by a photo analyst. The images in Figures 2.2.1.1 and 2.2.1.2 contain 512 two-meter pixels per line, and the image width on the ground is, therefore, 1024 meters or 1.024 km. At a scale of 1:50,000, this image would be only 20 mm wide.

2.2.2 Tonal Change: Approach No. 2

In order to reduce the level of detail from that resulting with Approach No. 1, the digital photo image data can be smoothed prior to all other processing operations. In this approach, a 13 x 13 pixel box filter is passed over the raw image data. Then, level slicing, theme production, theme outlining and outline compositing operations are performed. Figures 2.2.2.1 and 2.2.2.2 present the result. The level of detail is certainly reduced, but a new problem arises due to the effect of the smoothing filter on tonal boundaries where the tonal change is more than one step. In these cases it can be seen that a single boundary which crosses a measurement grid line will now produce several crossings of that grid line (see Figure 2.2.2.2). This leads to errors in the crossing count which are likely to be undesirable.

2.2.3 Tonal Change: Approach No. 3

In this approach, the raw digital image data are level sliced and themes are produced for each slice. Then, a version of the General Electric DIAL Theme Filter processing is employed. In its simplest form, the Theme Filter passes a square operator (odd number of pixels in each dimension) over every pixel in the multiple theme image. Each theme pixel is reassigned to the dominant

Figure 2.2.1.1 Tonal Change Boundaries, Approach No. 1, Subscene A

Figure 2.2.1.2 Tonal Change Boundaries, Approach No. 1, Subscene B

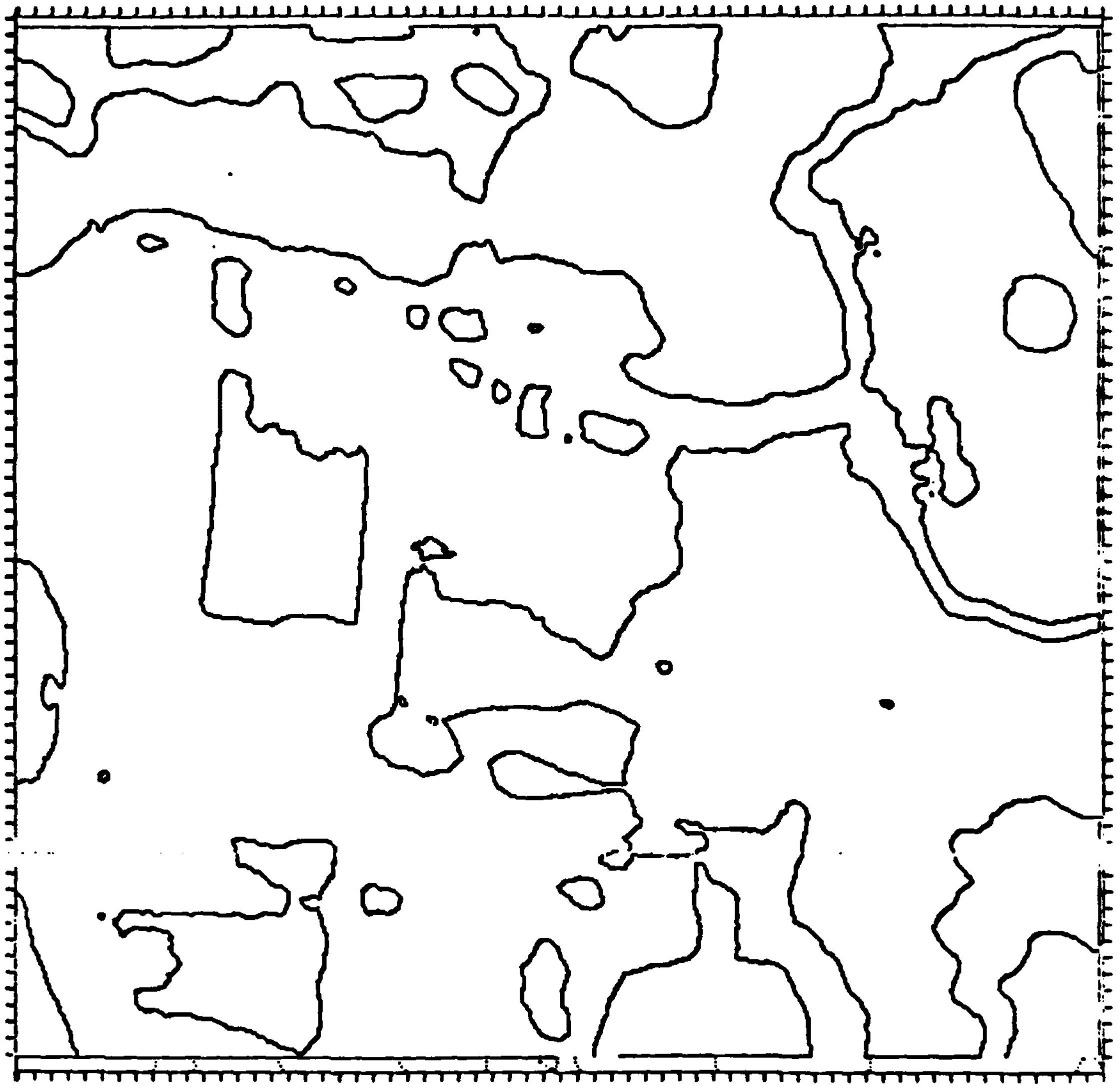

Figure 2.2.2.1. Tonal Change Boundaries, Approach No. 2, Subscene A

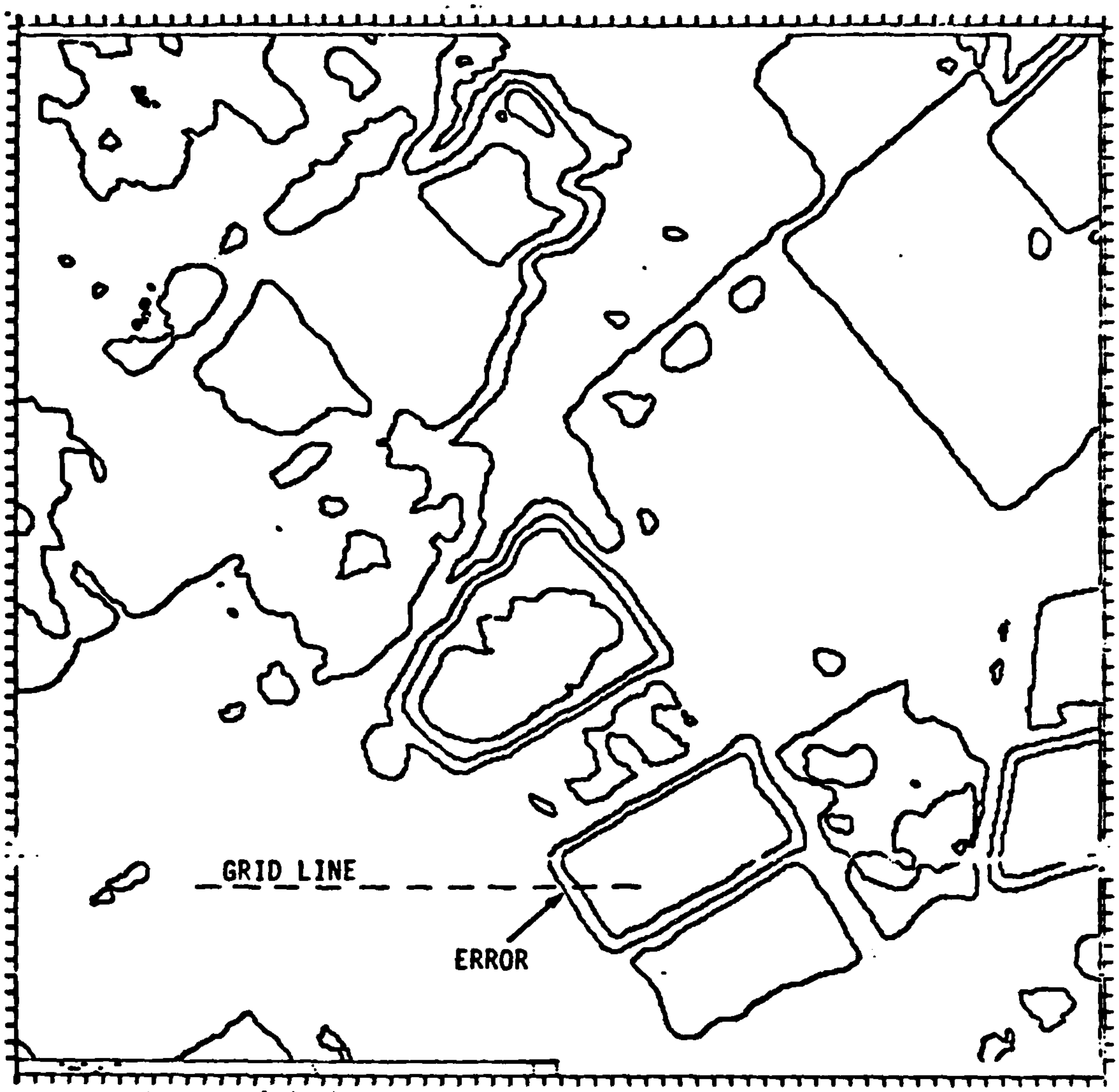

Figure 2.2.2.2. Tonal Change Boundaries, Approach No.2, Subscene B

theme within the boundaries of the operator. (If the pixel in question already corresponds to the dominant theme, then no change is made.)* This simplifies the multi-theme image, but does not create multiple themes at a tonal boundary where there is a tonal change greater than one step. The simplified themes are then outlined and the outlines composited. Several theme filters were tried with results as follows:

a. Two passes of a 5 x 5-pixel theme filter operator on a 512 x 512 pixel digital photo image. The resulting tonal boundary images for two subscenes are shown in Figures 2.2.3.1 and 2.2.3.2.

b. One pass of an 11 x 11-pixel theme filter. Figures 2.2.3.3 and 2.2.3.4 present the results.

c. Two passes of an 11 x 11-pixel theme filter. The results are shown in Figures 2.2.3.5 and 2.2.3.6.

Approach No. 3c appears to yield an output map suitable for making useful tonal change measurements. For each image to be analyzed for tonal changes, the Procedural Guide specifies that a uniformly spaced set of orthogonal grid lines be overlayed on the image and a count made for each grid line of the number of intersections of that line with tonal boundary lines. The grid lines are to be spaced at intervals corresponding to 600M in the scene, and the counts (or tonal changes) per line are to be normalized to changes per 1.2 km. For the images analyzed in the investigation described here, the grid line length (or image width) is 512 pixels x 2M/pixel or 1024M. Therefore, the counts per line are multiplied by 1200M/1024M = 1.17 to accomplish the normalization. By averaging the normalized count for all grid lines in the image, per the Procedural Guide, a value is obtained which is a measure of the number of tonal changes in the image. Results for the two subscenes analyzed using Approach No. 3c are presented in the two tables which follow. Construction of the grid lines, and counting of intersections, was performed manually, but the process could be fully automated if desired.

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* Further, if the pixel does <u>not</u> correspond to a dominant theme, but is part of a small or narrow theme such as a stream which should be accounted for when measuring tonal changes, the filter is designed to ensure that the pixel is <u>not</u> reassigned to the dominant theme.

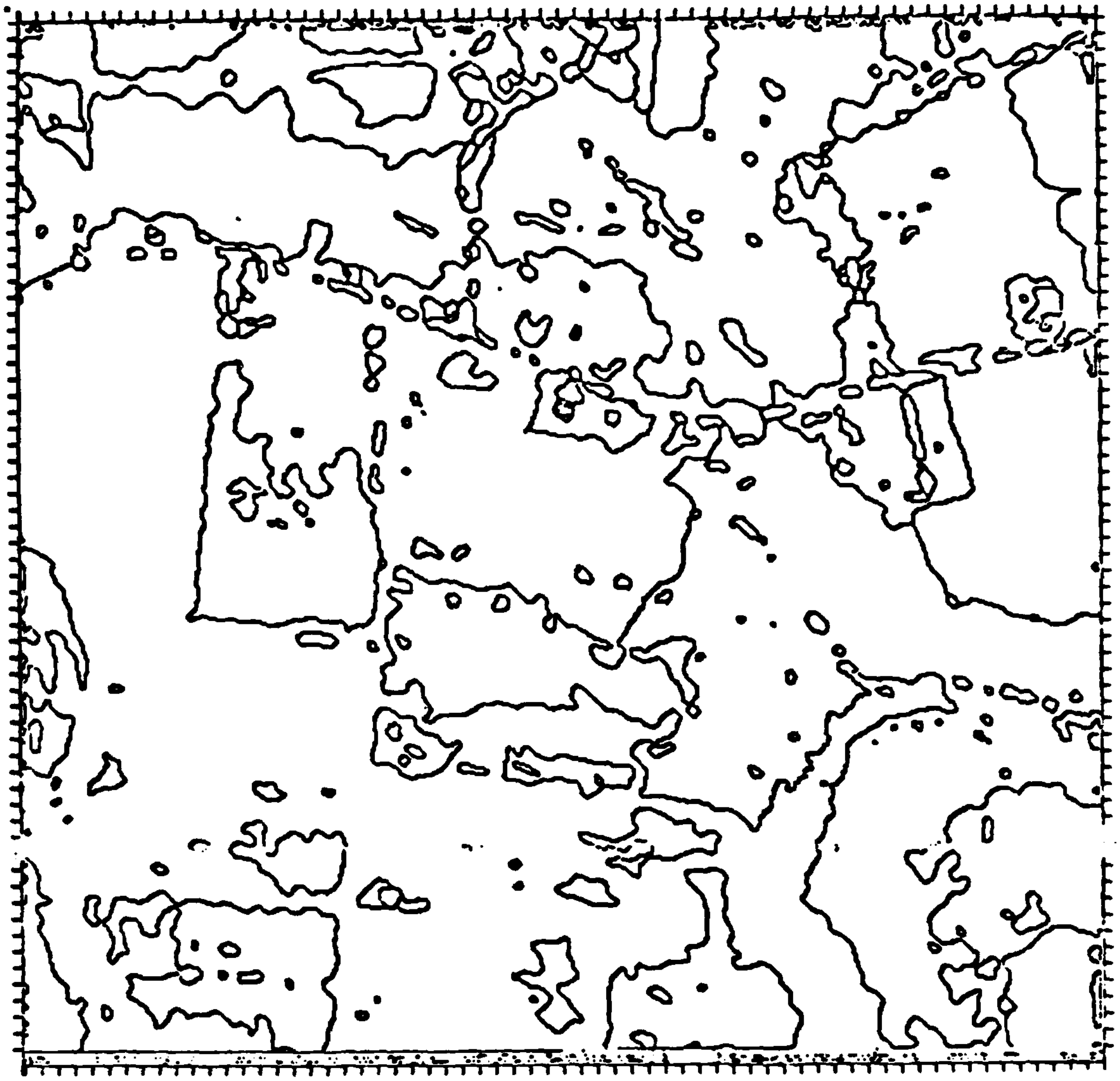


Figure 2.2.3.1. Tonal Change Boundaries, Approach No. 3, 5 x 5 Filter, Subscene A

Figure 2.2.3.2. Tonal Change Boundaries, Approach No. 3, 5 x 5 Filter, Subscene B

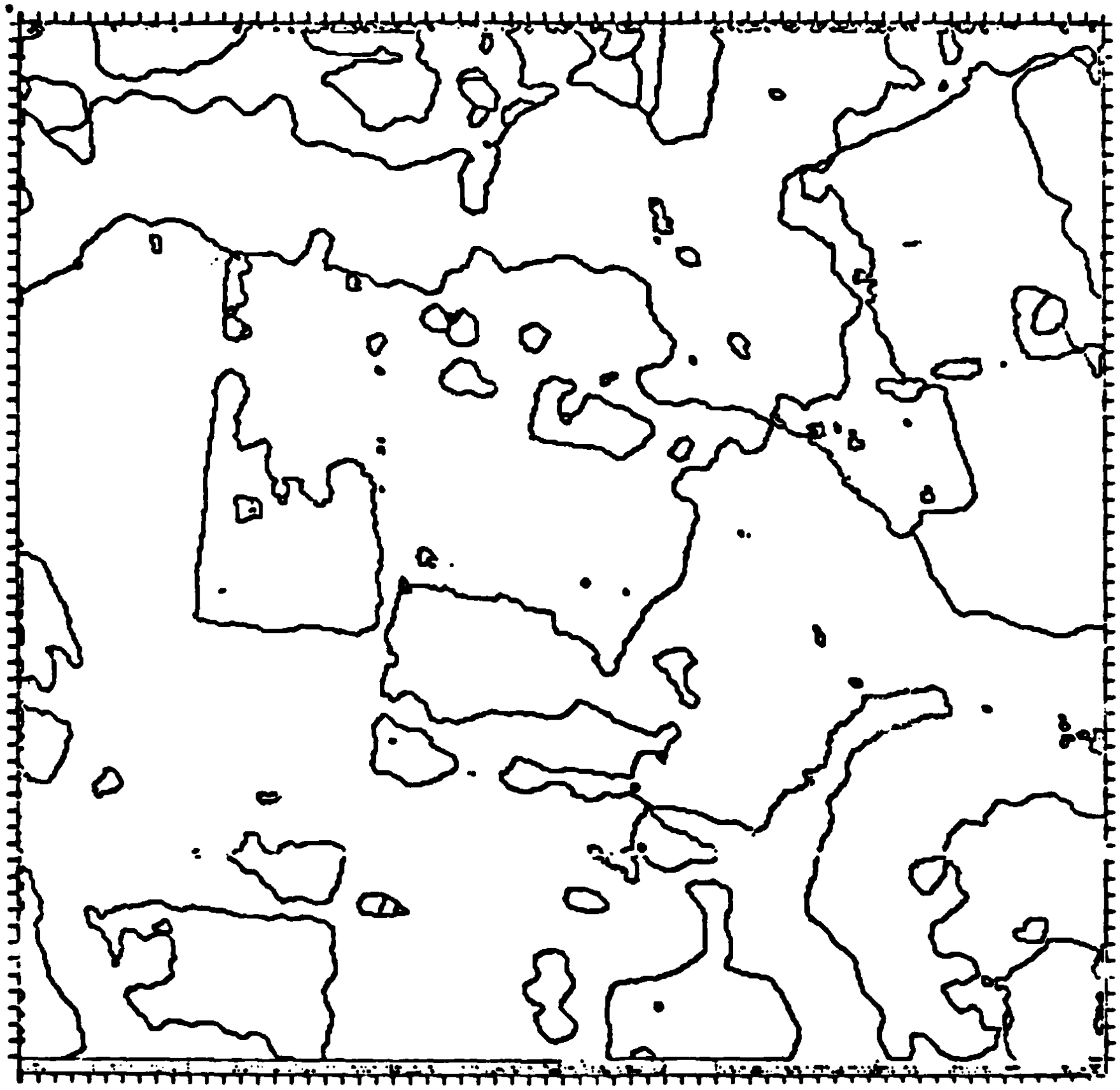


Figure 2.2.3.3. Tonal Change Boundaries, Approach No. 3, One Pass 11 x 11 Filter, Subscene A

Figure 2.2.3.4. Tonal Change Boundaries, Approach No. 3, One Pass 11 x 11 Filter, Subscene B

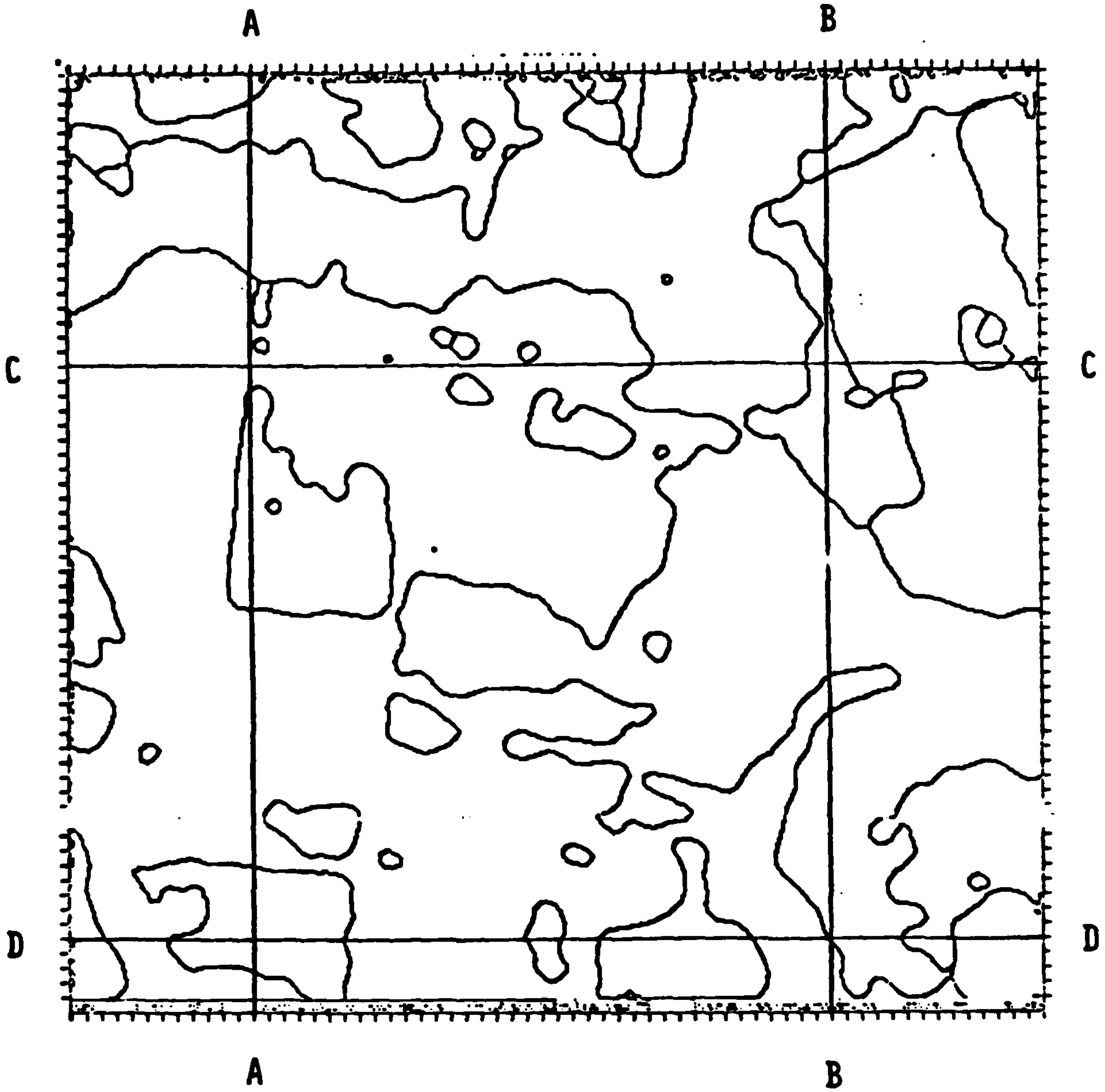


Figure 2.2.3.5 Tonal Change Boundaries, Approach No. 3, Two Passes 11 x 11 Filter, Subscene A

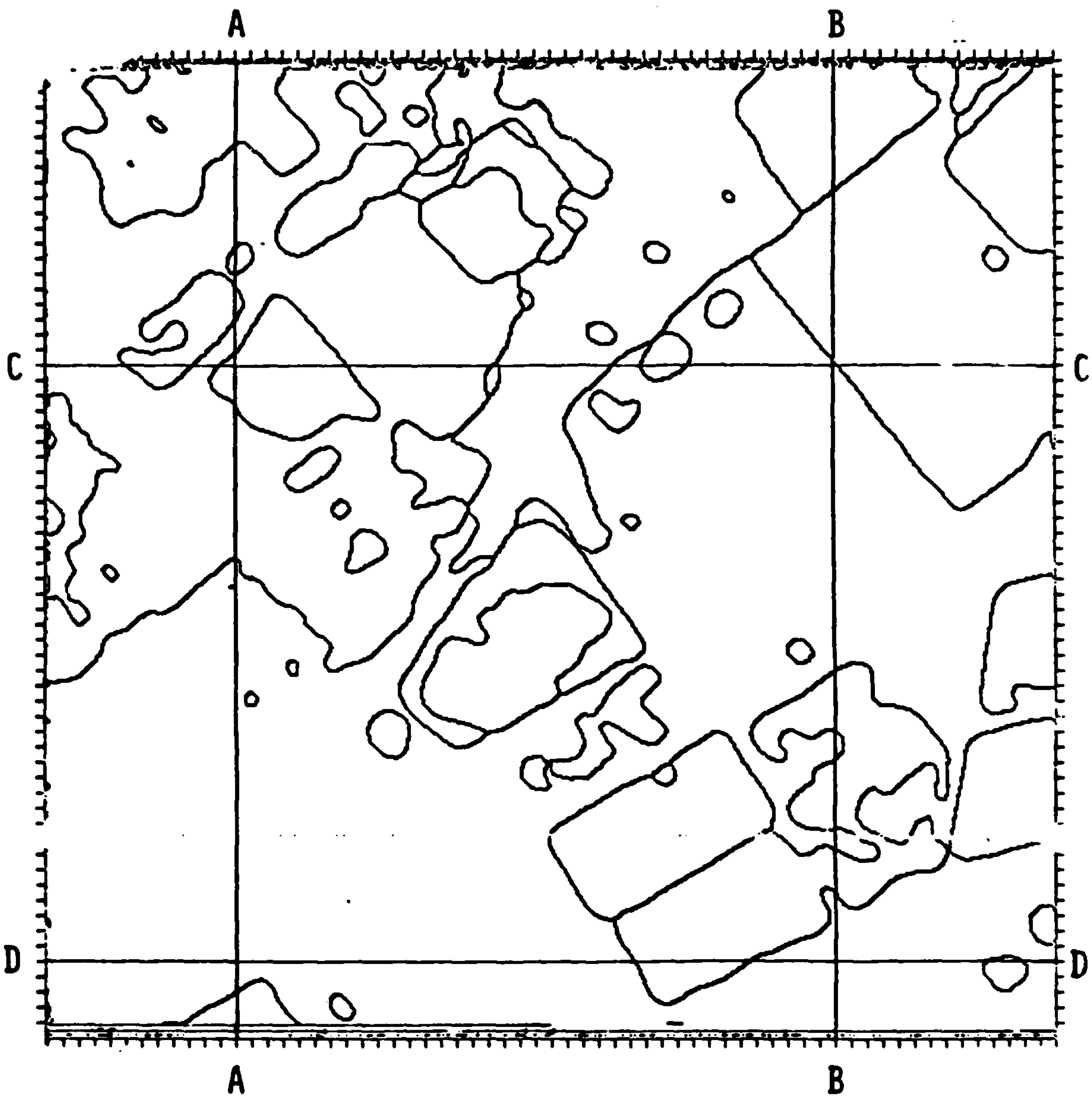


Figure 2.2.3.6 Tonal Change Boundaries, Approach No. 3, Two Passses 11 x 11 Filter, Subscene B

Summary of the Number of Tonal Changes - Subscene A*

Line Segment	No. of Changes**	No. of Changes/1.2km***
A-A	7	8.2
B-B	7	8.2
C-C	6	7.0
D-D	10	11.7
		Average = 8.8

Summary of the Number of Tonal Changes - Subscene B*

Line Segment	No. of Changes**	No. of Changes/1.2km***
A-A	9	10.5
B-B	8	9.4
C-C	9	10.5
D-D	4	4.7
		Average = 8.8

* See text for description of procedure.

** No. of changes over total line segment = changes/512 pixels = changes per 1024 meters.

*** No. of changes over total line segment x 1200/1024.

2.3 Point and Linear Obstacles

2.3.1 Introduction

Point obstacles are described in the Procedural Guide as small surface irregularities, greater than 1.5 meters high, showing a high amount of symmetry in plan view. These include such obstacles as boulders, pinnacles, sharp-pointed ridge crests and pointbars. Linear obstacles are elongated surface irregularities, which show greater than 1.5 meters of relief, and exhibit near vertical faces. Examples include rock outcrops, sharp ridge crests, terrace edges, landslide scarps, gully walls and man-made obstacles such as quarries and roadcuts. As noted previously, detection of these features generally requires elevation information such as that from digital stereo imagery or other sources. Radar imagery may be useful. Otherwise inference must be used, or a specialized, non-general technique used.

Since no imagery with elevation information was available, and no radar imagery for a scene with point or linear obstacles, a specialized approach was examined briefly. This involved the use of a scene in which there was direct sunlight and thereby shadow information. A digital photo image of a Fort Belvoir scene was selected. This image is shown in Figure 2.3.1. The sun azimuth is such that shadows are essentially orthogonal to, and below, scan lines containing a feature of interest. This orientation simplifies the digital analysis of a feature and its shadow, but implementation for other sun azimuth angles is certainly feasible. The sun elevation is approximately 45 degrees, and a scene pixel has linear dimensions of about 2.5 feet. Thus, an obstacle 1.5 meters high would cast shadows two pixels long. In the tests performed here, the search was optimized for shadows three pixels long.

2.3.2 Point Obstacles

The following template with weighting factors as shown was passed over every pixel in the digital image in a search for point obstacles.

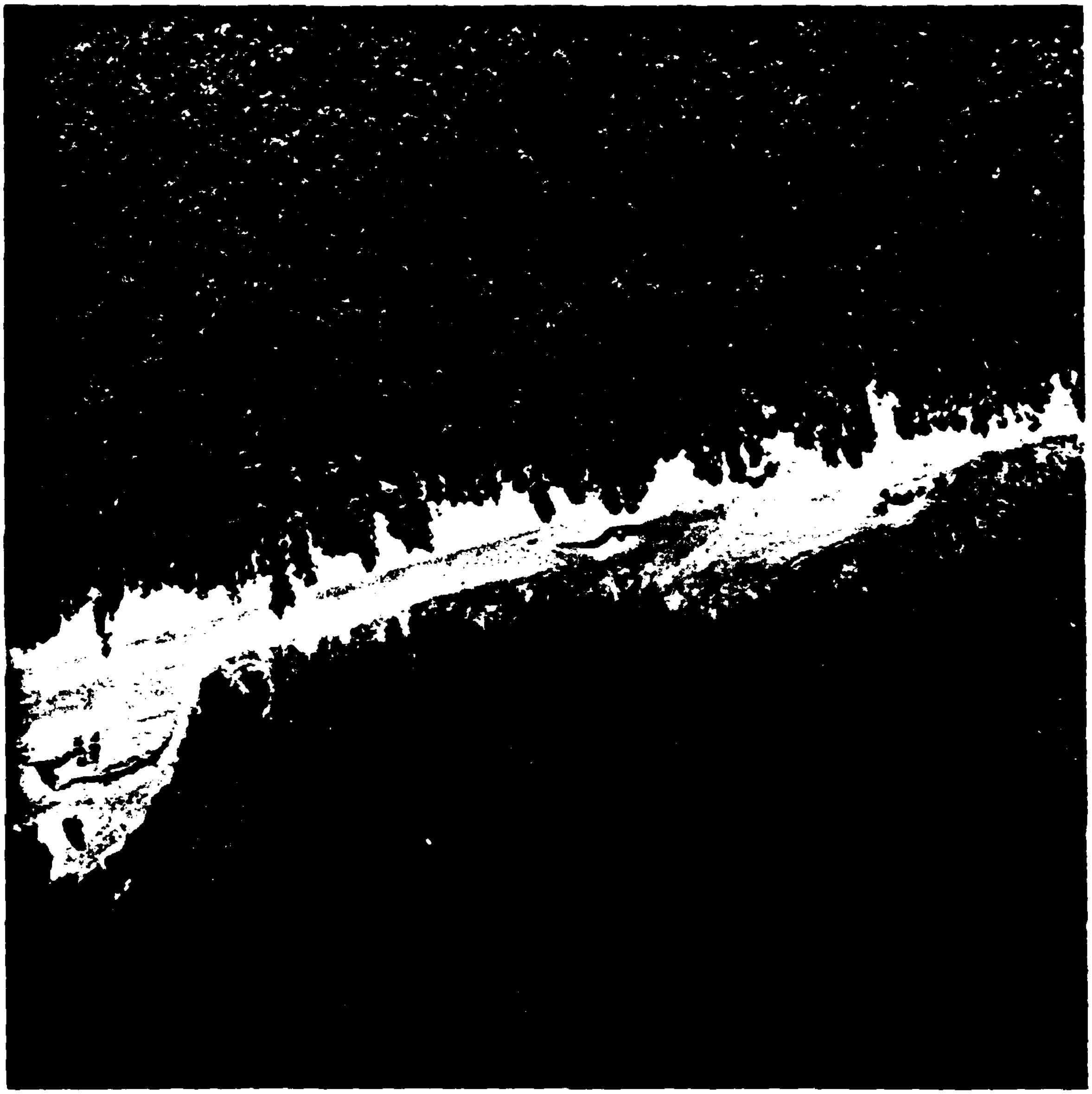


Figure 2.3.1 Digital Photo Image Used for Obstacle Detection Tests

	-3	-2	-1	0	1	2	3
3							
2							
1							
0				2.000			
-1				-0.066			
-2				-0.067			
-3				-0.067			

Actually, an interactively determined gray-level range was specified for the pixels being tested for point obstacles, and this range had to be satisfied concurrently with the template operation. Use of the gray-level range minimizes false alarms in the point obstacle detection process.

The output of the template is a gray-level image (Figure 2.3.2.1) which is then thresholded to produce a binary map (theme) in which likely locations of point obstacles are each represented by a cluster of a few pixels. The process works reasonably well, although false alarms do exist. However, a further processing step is necessary. Examination of the point obstacle template will show that the template also will extract linear obstacles oriented along the scan line. This ambiguity was resolved by subtracting the binary map showing linear obstacles (see the following section) from the binary map produced by the point obstacle template. The result is a binary map showing likely locations for point obstacles. This map is shown in Figure 2.3.2.2. The false alarms occur at the boundary between the forest and open area, and they correspond to certain light features adjacent to dark features which just happen to fall within the gray range and the spatial orientation used in the machine search for point obstacles.

2.3.3 Linear Obstacles

The search for linear obstacles involves a procedure very similar to that for point obstacles. The following template was used:

	-3	-2	-1	0	1	2	3
3							
2							
1							
0		0.600	0.600	0.600	0.600	0.600	
-1		-0.200	-0.200	-0.200	-0.200	-0.200	
-2		-0.200	-0.200	-0.200	-0.200	-0.200	
-3		-0.200	-0.200	-0.200	-0.200	-0.200	

As the template passes sequentially over every pixel in the image the template output forms a gray-level image (Figure 2.3.3.1). This image is thresholded such that pixels with the highest levels (most closely resembling the template) form a binary (theme) map with the pixel clusters representing likely locations of linear obstacles. Primarily, of course, only those obstacles are detected which are oriented in the direction established by the template. Figure 2.3.3.2 shows the locations of the linear obstacles detected in this particular case. Some are false alarms, and these are identified. They occur at the boundary of the forest and open area and at the boundary of the road and open area. The same circumstances causing the point obstacle false alarms are involved in producing these linear obstacle false alarms.

2.4 Summary

The investigation of extraction of Surface Roughness information, as has been described here provides some optimism but has only scratched the surface of available techniques with potential. Not only do the techniques which were examined here need to be developed and assessed more thoroughly, and evaluated in more scenes, but use of imagery providing elevation information, and the development of associated extraction techniques, needs to be pursued as well.

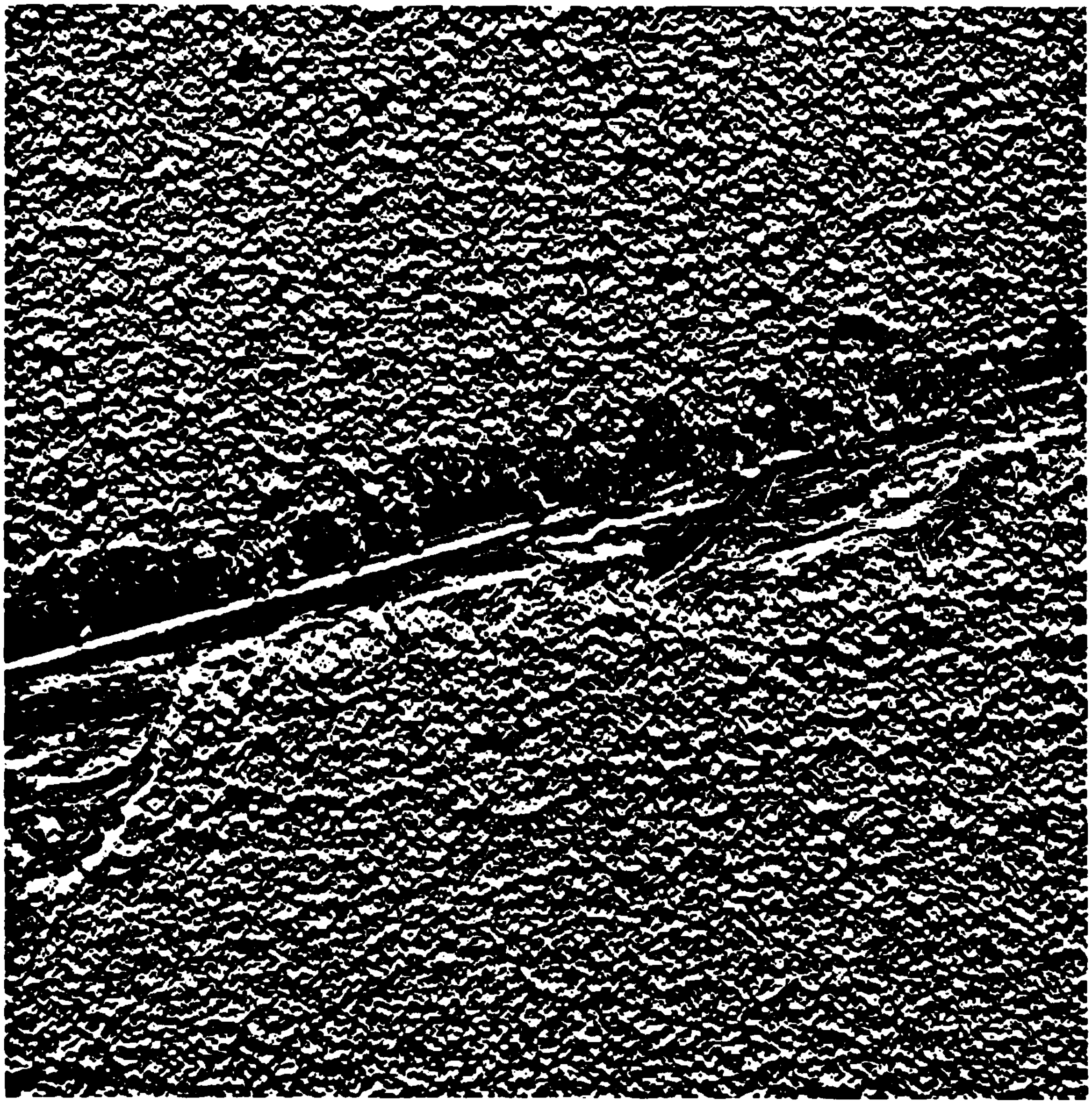
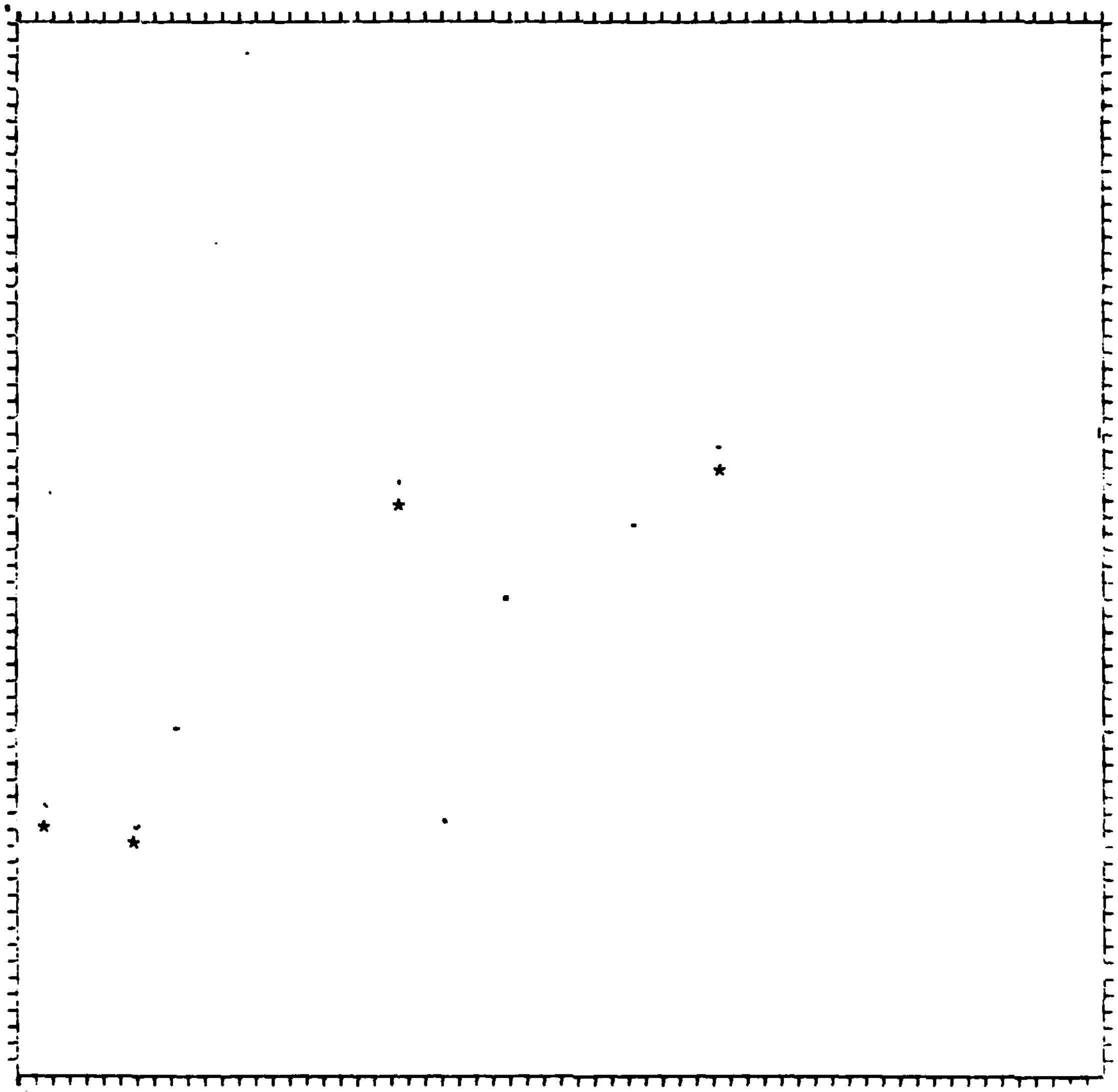


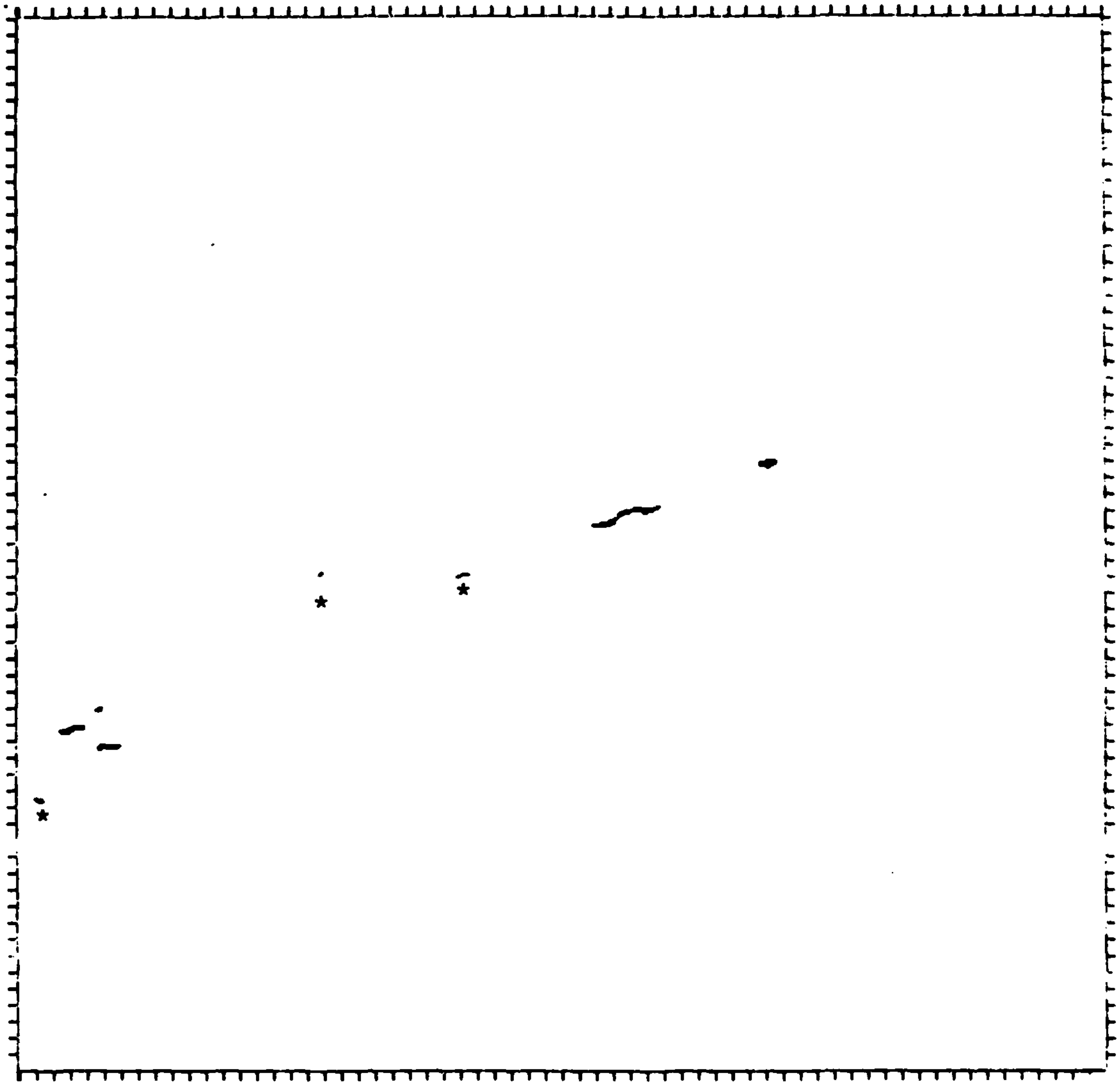
Figure 2.3.2.1 Digital Image Produced From Output of Point Obstacle Template



*False Alarms

Figure 2.3.2.2. Detection of Point Obstacles

Figure 2.3.3.1 Digital Image Produced from Output of Linear Obstacle Template



*False Alarms

Figure 2.3.3.2. Detection of Linear Obstacles

3. MULTI-PLANE IMAGE DATA BASE WITH PHOTOMOSAIC

3.1 Introduction

A great deal of environmental data are currently available to decision makers. The increasing trend is to incorporate these data in a computerized geographically oriented system. The steps involved in producing a geographical information system include:

a. Conversion of the data to a machine readable form.

b. Structuring of the data in a manner capable of being processed efficiently.

c. Preparation of computer programs for retrieval, analysis, and/or display of the data.

The task described here is concerned primarily with the second of these steps and, to a limited extent, the third step.

The data can be structured in various ways and this has important implications for the type of problems which are most efficiently attacked. One of the objectives of the Terrain Data Extraction Study has been to investigate the feasibility of using interactive digital processing in the generation of certain map products. Accordingly, this phase of the study involves a demonstration of factor overlay production using the techniques developed to date on a map-sized area. The multi-plane data base concept evolved from this consideration. The use of multiple data planes in image files facilitates not only image categorization, but the interchange and logical manipulation of the resulting thematic maps. Extracted information can be rapidly aggregated by various administrative and physical units or areas defined by map boundaries. For the present task, the data base has been designed to contain data for the same scene from the following sources:

a. Mosaic of several overlapping digitized aerial panchromatic photographs.

b. Digital airborne SAR radar imagery.

c. Thematic Mapper digital imagery acquired by Landsat 4.

The field-of-view for frames of aerial photography, and the associated digitizing resolution, are such that a mosaic of several frames is necessary to obtain a map-sized image. Thus, a digital mosaicking procedure for the aerial photography becomes an important part of assembling the data base. Algorithms developed in Phase 4 of this program are used for the mosaicking operation.

The site selected for coverage by all the data base imagery is in the vicinity of Elizabeth City, NC.

3.2 Data Base Structure

General Electric's Digital Image Analysis Laboratory (DIAL) is the test bed for establishing the prototype multi-plane data base and demonstrating its feasibility and capability. Consequently, the digital image file structure that is routinely used on the DIAL system becomes a logical choice for the data base. The GE DIAL uses the raster scan file format to store image data in band-interleaved-by-line (BIL)* fashion for multi-channel imagery. It offers ease of retrieval of spatially registered information and the ability to perform operations on a pixel basis, thus utilizing the finest resolution of the information available.

The number of data planes to be assigned to the data base depends upon:

a. Number of data sources to be accommodated.

b. Number of data planes needed to derive and store intermediate results, and

c. Number of data planes needed to store the binary thematic information for the factor overlays to be produced.

---

* BIL format for an image with n spectral bands or channels:

```
    File line 1   = Image line 1, band 1
    File line 2   = Image line 1, band 2
    File line n   = Image line 1, band n
    File line n+1 = Image line 2, band 1
    File line n+2 = Image line 2, band 2
         etc.              etc.
```

The size of each data plane depends upon the quantity of data resulting from data resolution and coverage needed to produce map size products. Obviously, there has to be a trade-off of some sort when the total storage needed is excessive for the processing system and/or the application programs to manipulate efficiently.

The multi-plane data base structure selected is depicted in Figure 3.2.1. Steps in arriving at the specific structure, and other details of the structure, are as follows:

a. One image line in a data base plane = one record. Each byte in that record corresponds to one pixel and carries the value of that pixel in a single band. The value has a range of 256 levels or 8 bits.

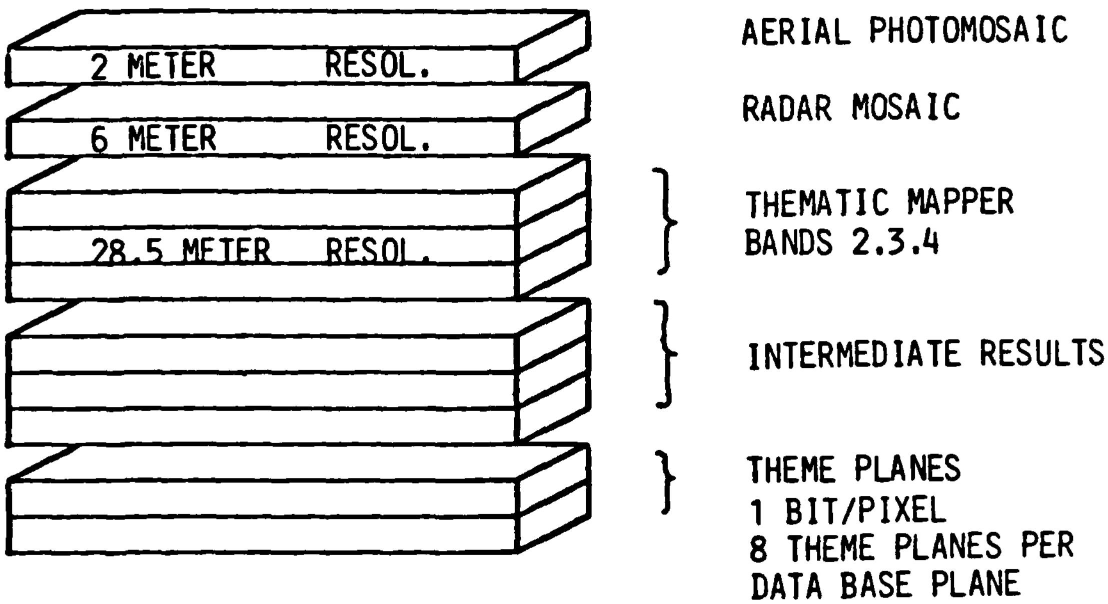
b. The GE DIAL File Access software handles a maximum of 4096 bytes per record.

c. In order to approach a data base storage of map-sized images, one of which is comprised of a mosaic of several digitized aerial photos, the maximum line length of 4096 pixels (bytes) is selected.

d. It is estimated that the data base should contain 10 image planes with 8 bits (1 byte) per pixel in each plane. The 10 planes will accommodate the image data sources (photo, Thematic Mapper, radar), provide workspace (intermediate results), and include two planes for binary map (theme) output images. The binary map images contain only one bit/pixel, so that for these images one data base plane can accommodate 8 bit planes.

e. The GE DIAL system uses RP06 disk packs for mass storage. These have a maximum useable capacity of 176MB. To have the data base contained in one disk pack, it can be determined that 10 image planes of 8 bits (1 byte) per pixel can be accommodated, with 4096 pixels per line and 4096 lines in each plane. 10 planes x 4096 x 4096 bytes = 160 MB, close to maximum disk capacity. (1 MB = 1024 x 1024 bytes.)

f. With 2M digital photo resolution (highest resolution of all images in the data base), the maximum scene size that can be stored is (2 x 4096)M x (2 x 4096)M or 8.19 Km x 8.19 Km. For 1:50,000 scale maps, this is a map whose size is 0.16M square or 6.5 inches square. This



- 10 PLANES
- 4096 X 4096 PIXELS/PLANE
- 8 BITS/PIXEL

Figure 3.2.1 Multiplane Data Base Structure is not as large as standard maps, but it is the compromise selected when given the system limitations noted previously. Larger map sizes are possible using fewer data base planes, larger disk capacity, or lower photo resolution (greater than 2M).

g. The data base was established as a single file containing 327,680 disk blocks of image data plus a 2-block information label and a 1-block index. Each block corresponds to 512 bytes. Thus, for the image data, 8 blocks per line (4096 pixels) x 4096 lines x 10 planes = 327,680 blocks.

h. The data base structure is such that the same pixel location can be accessed simultaneously in each plane. Thus, multi-channel information is available for each pixel.

3.3 Aerial Photomosaic

3.3.1 Accuracy Considerations and Imagery Description

The accuracy required for a mosaic depends upon its intended use. Though a precision camera is an essential element of a photomosaic project, the accuracy of the mosaic can be no better than the control used and the techniques employed in its compilation. Normally, a 60% forward overlap and 30% side overlap are used in aerial photomosaics. Accuracy can be increased by increasing the amount of overlap so that only a smaller central portion of each photograph is used, thereby reducing displacements due to relief and minimizing mosaic degradation due to other factors. Briefly, some other important factors that affect the accuracy are:

a. Type of terrain and its relief
b. Scale of the original photographs
c. Type and focal length of camera
d. Extent of control used.

The focus of this task has been to assemble a digital mosaic of aerial photographs supplied by USAETL. The following two sections describe the aerial imagery and the relevant reference imagery that were used to extract ground control information.

3.3.1.1 Aerial Imagery

Four panchromatic aerial photographs acquired by USAETL were supplied to General Electric in the form of digital data on magnetic tape for mosaicking purposes. These overlapping frames (58, 59, 47 and 94) cover an area in the vicinity of Elizabeth City, North Carolina. The aerial camera employed to take these photographs had a focal length of 6 inches, and the scale of the photographs was 1:20,000. The photographs were digitized by USAETL using an Optronics scanner/digitizer system with a 100 micron resolution. This resulted in a ground resolution of 2 meters in the digital data.

The relative locations of these overlapping photographs is indicated in Figure 3.3.1.1. Each tape file contained an image of 2048 scans with 2048 pixels per scan for a photograph. The total overlapped width of the ground covered is, then, more than 4096 pixels across and cannot be accommodated in the data base unless trimmed some way. A decision was made to trim frames 47 and 94, as indicated by dotted lines, at the time of assembling a mosaic. Once these boundaries have been established, the required reference image subscene can be determined.

3.3.1.2 Reference Imagery

The main purpose of a reference image is to acquire ground control information that is essential to assure that each feature in the mosaic is located in its proper horizontal position relative to all other features. The accuracy of ground control information is very important and directly impacts the accuracy of a mosaic.

General Electric procured a Thematic Mapper (TM) digital image of the area covering Elizabeth City, NC acquired by Landsat 4 on September 24, 1982. The scene identification number for this image is 40070-15081, with Landsat World Reference System path and row numbers of 14 and 35 respectively. The value of this TM image is that it provided the most accurate reference available with a ground resolution of 30 meters. A sub-image covering the overlapping aerial photographs within the dotted outline illustrated in Figure 3.3.1.1 was

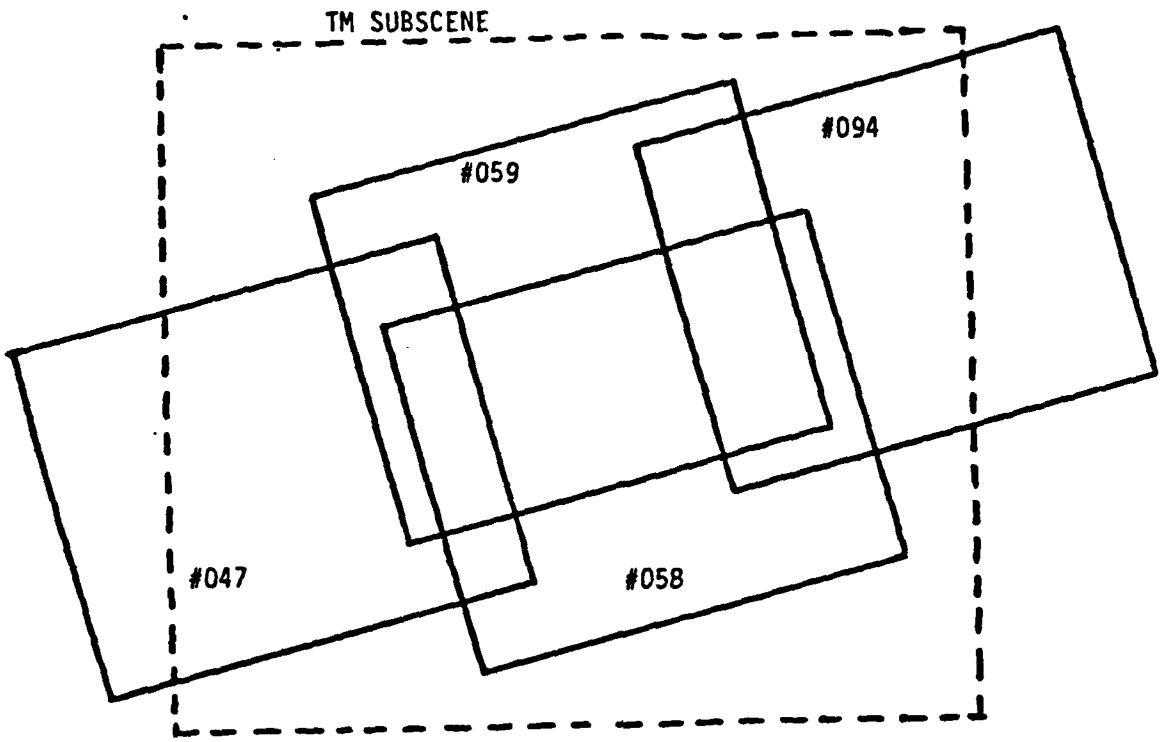


Figure 3.3.1.1. Relative Locations of Photo Images

extracted and resampled to obtain the 2-meter resolution present in the digitized aerial photography. The resampling was based on the assumption that the aerial imagery under consideration had a 2-meter resolution and that the TM image had a 28.5-meter resolution. The north-west corner of the sub-image (or window) extracted from the TM image was pixel 3129 on line 2349. The window size selected was 293 pixels by 293 lines so that the resampling to yield a 2-meter resolution with a replication factor of 14.5 would fit within a 4088 x 4085 pixel plane of the data base.

Although the TM image was acquired at a different time of the year than that of the aerial imagery, almost all of the ground features that are in the digitized aerial image are identifiable in the TM band 3 and 4 images and these TM bands* were used in extracting the ground control points. Later, the TM band 2* image was added to the data base to be available, along with TM bands 3 and 4, for scene analysis in the future. Band 3 of the (reference) TM sub-image stored in the data base is shown in Figure 3.3.1.2.

3.3.2 Image Rectification

An aerial photograph is almost always tilted by a small amount since there is no mechanism available to hold a camera in a perfectly vertical position at the time of exposure. Depending upon the magnitude of tilt present, an aerial photograph may have to be rectified before its intended use. The rectification process removes the undesirable effects of tilt, such as displacement of ground features, and derives an equivalent vertical photograph. The ground features are correctly located in their proper horizontal positions relative to each other on an equivalent vertical photograph. The mosaicking algorithm developed in Phase 4 of this program accomplishes rectification of a digitized aerial photograph in the following steps:

* Spectral ranges for TM bands 2, 3, 4 are, respectively: 0.52-0.60uM; 0.63-0.69uM; 0.76-0.90uM.

Figure 3.3.1.2 Band 3 of the Reference TM Sub-Image

a. Derivation of a linear transform relating an aerial image to the reference image utilizing the ground control information,
b. Determination of photographic tilt, swing and azimuth parameters for an aerial image, and
c. Un-tilting of an aerial image to produce an equivalent vertical image.

The mosaicking algorithm takes one more step to enable compilation of an aerial mosaic, and that is:

d. Rotation of the equivalent vertical image for its registration with the reference image.

3.3.2.1 Ground Control Information

The ground control information was acquired interactively by locating the identical features on the reference image and aerial image. The coordinates of such features were obtained in terms of pixels and lines. An effort was made to identify three or more control points in the overlapping area of adjacent photographs. The reference image was at lower resolution (28.5 meters) compared to the aerial imagery(2 meters) and, at best, a TM sub-pixel accuracy was possible by this approach. At least 16 control points were extracted for each aerial image since the mosaicking algorithm accepts up to 16 control points. A plot of the reference image control points is given in Figure 3.3.2.1 to indicate their distribution over the individual aerial images shown in unique outlines. Tables 3.3.2.1.1 through 3.3.2.1.4 list the control points used to accomplish rectification of the four digitized aerial photographs supplied by USAETL.

3.3.2.2 Tilt Prediction

The control points are used to establish a relationship between an aerial image and the reference image and, subsequently, to predict the photographic tilt and the associated swing angle. A linear model was employed to establish the relationship, and a least squares formulation was derived to determine the

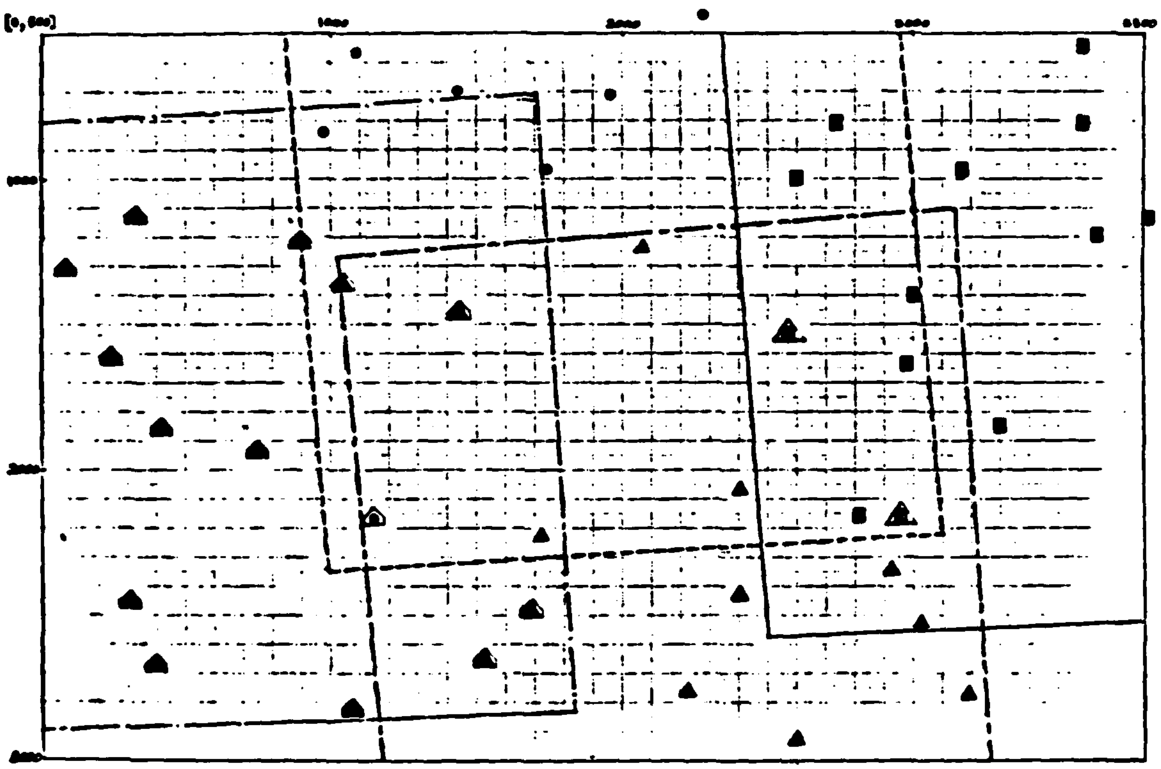


Figure 3.3.2.1. Control Point Locations

Table 3.3.2.1.1. Control Points for Image GE59 (Photo No. 59)

No.	Aerial Image	Reference Image
1	1175,954*	2069,1239**
2	1139,401	1965,710
3	127,407	979,839
4	144,948	1043,1363
5	265,148	1092,563
6	1403,1810	2410,2068
7	1899,602	2739,809
8	1492,142	2282,420
9	1640,1305	2572,1534
10	1922,1952	2958,2162
11	167,1737	1152,2162
12	619,329	1441,699
13	721,1867	1724,2231
14	523,1139	1446,1459
15	1790,769	2644,999
16	887,663	1748,966

* Pixel No., Line No. in digital image coordinates.

** Pixel No., Line No. in data base coordinates.

Table 3.3.2.1.2. Control Points for Image GE60 (Photo No. 94)

No.	Aerial Image	Reference Image
1	323,430*	2739,808**
2	216,593	2644,999
3	61,1120	2572,1534
4	340,1779	2958,2162
5	308,1962	2929,2344
6	438,1284	2981,1635
7	724,1544	3305,1848
8	1181,579	3592,812
9	1351,907	3822,1130
10	1534,808	3990,986
11	1204,298	3585,537
12	1162,959	3638,1193
13	503,1051	3005,1397
14	221,1777	2817,2155
15	715,647	3171,972

* Pixel No., Line No. in digital image coordinates.

** Pixel No., Line No. in data base coordinates.

Table 3.3.2.1.3. Control Points for Image GE61 (Photo No. 58)

No.	Aerial Image	Reference Image
1	4,107*	1043,1362**
2	606,1052	1724,2231
3	1293,773	2410,2067
4	1815,1119	2958,2162
5	1522,461	2572,1534
6	394,304	1446,1458
7	1050,107	2069,1239
8	1787,1304	2929,2344
9	1851,1515	3029,2528
10	1968,1873	3194,2872
11	364,1472	1531,2656
12	1497,1852	2704,2928
13	1357,1348	2508,2425
14	1145,1664	2329,2761
15	531,1314	1686,2481

* Pixel No., Line No. in digital image coordinates.

** Pixel No., Line No. in data base coordinates.

Table 3.3.2.1.4. Control Points for Image GE62 (Photo No. 47)

No.	Aerial Image	Reference Image
1	1521,501*	1043,1362**
2	1889,714	1446,1458
3	1494,1308	1152,2162
4	1973,1754	1686,2481
5	1791,1908	1531,2656
6	1116,1010	749,1937
7	627,1704	398,2675
8	1284,2000	1074,2829
9	685,592	244,1613
10	861,137	329,1127
11	585,274	86,1310
12	563,1442	310,2459
13	805,876	416,1862
14	1393,553	898,1219

* Pixel No., Line No. in digital image coordinates.

** Pixel No., Line No. in data base coordinates.

best fit to the control points to get the linear transformation.* The mosaicking algorithm accepts up to 16 control points, and the resulting transform is used to calculate the reference image coordinates corresponding to the corner points of the aerial image. The calculated data points are used to predict the photographic tilt, swing, azimuth and the translation vector for the aerial image with respect to the reference image. The reasoning is that the calculated data points are expected to be more accurate than the interactively acquired control points. By using the fiducial marks on the aerial imagery, principal points were determined for the four aerial images.

The photographic tilt and the associated parameters predicted for the four aerial images under consideration are given in Table 3.3.2.2.

Table 3.3.2.2. Photographic Parameters

Image Id.	Tilt (Deg.)	Swing (Deg.)	Azimuth (Deg.)	Translation (X,Y)	Principal Pt. (x,y)
GE59	0.030	15.55	- 7.04	1833,1238**	939,911***
GE60	-1.077	49.81	- 8.85	3429,1195	947,909
GE61	-1.314	47.69	- 6.98	2062,2115	934,954
GE62	-1.217	50.00	-11.07	573,1892	947,931

** Pixel No., Line No. in data base coordinates.

*** Pixel No., Line No. in digital image coordinates.

* The model was developed in Phase 4 of this program. For a description of the model, refer to Section 3.3, Projective Transformation Equations, in the Phase 4 technical report. That report is ETL-0348, Interactive Digital Image Processing for Terrain Data Extraction, Phase 4, November 1983. In Phase 5, the phase reported here, the model is implemented using actual control point data to arrive at the linear transformation relating the specific aerial and reference images.

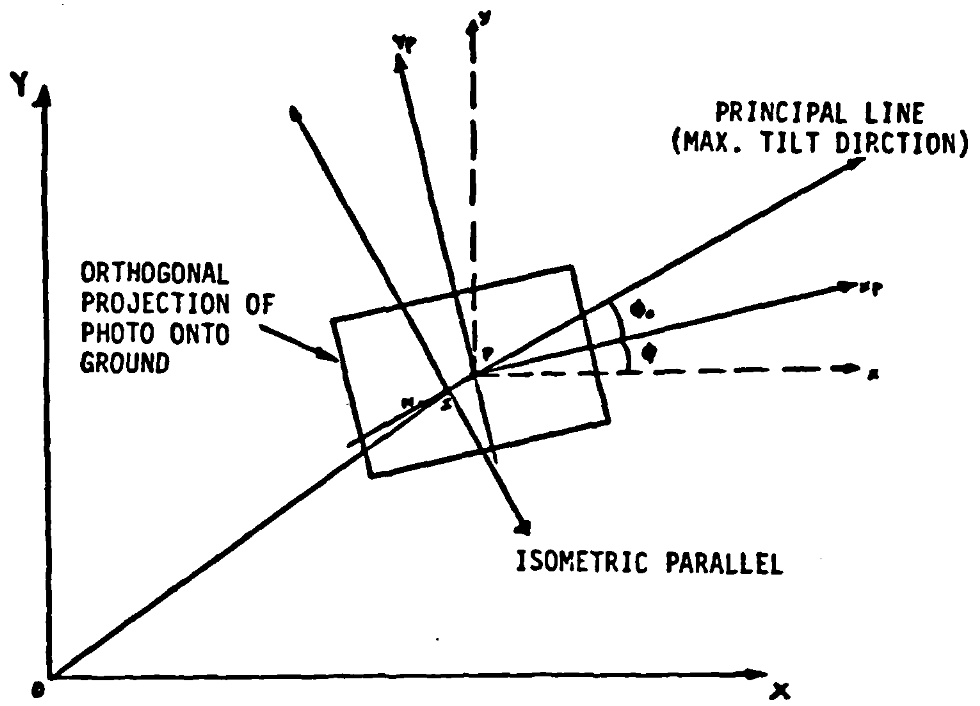
3.3.2.3 Correction for Tilt

The effect of the photographic tilt is manifested by displacement of ground features and changes in the shapes of areas on the photograph. Refer to Figure 3.3.2.3. Displacement due to tilt is radial from the isocenter. It varies with the square of the radial distance and with the cosine of the angle that a line through the image and the isocenter makes with the direction of tilt. The displacement is positive on one side of the photograph and negative on the other side. There is a line on the photograph that does not get displaced as a result of tilt, and this line is called the isometric parallel. The principal line indicates the direction of maximum tilt and forms an orthogonal system with the isometric parallel, with the isocenter as the origin.

The mosaicking algorithm exploits this fact to remove the tilt distortion effect. It rotates the aerial image by using the binary shear technique to get the scan direction along the isometric parallel. The procedure then removes tilt displacement sequentially for each scan line, and rotates the resulting image back to its original scan direction. These operations produce an equivalent vertical image of the input aerial image. The equivalent vertical image can be rotated again to orient its scan lines with those of the reference image in order to assemble an aerial mosaic registered to the reference image.

3.3.2.4 Relocation in the Data Base

The rectified and registered image is placed in the data base plane using the isocenter offset calculated at the time of tilt prediction. Throughout the tilt correction step, the location of the isocenter is tracked in order to accomplish this. There is overlap among the aerial images, and registration may be verified by viewing the overlap area in two images simultaneously. To do this, each rectified image is stored on a separate plane in the data base using the isocenter offsets for relocation. The planes can be viewed on the display unit at full resolution for such verification.



Two- Dimensional Model

X, Y = Map Coordinate System

Xp, Yp = Photo Coordinate System

P = Principal Point

I - Isocenter

Figure 3.3.2.3

Relationship of an Aerial Photograph to the Map

3.3.3 Mosaicking

The rectified aerial images with the appropriate relocation in the data base are already registered to the reference image. There is a considerable amount of overlap between most adjacent images. This overlap is removed during mosaicking. Generally, for the adjacent images, a boundary in the overlapping area is identified such that it is approximately equidistant from the centers of the images, with the best registration of common features. The analyst selects such a boundary interactively, as described in the following section.

3.3.3.1 Imagery Merging

The digital rectified aerial images, stored on different planes of the data base, are merged together by viewing the overlapping areas and identifying a piece-wise linear boundary. This is a staircase-like boundary comprised of line segments alternately parallel and perpendicular to the image scan lines. The "steps" need not be uniform. The boundary is chosen for the best radiometric match between the images being merged. The analyst starts with two images, identifies a boundary and merges the two images by transferring the data within this boundary to the mosaic plane. In a similar way, the next image is merged with the image in the mosaic plane, and the procedure is repeated for the remaining images.

3.3.3.2 Radiometry Matching

Although the four aerial photographs under consideration were acquired by using the same aerial camera and later digitized using the same scanner/digitizer under similar conditions, there was a visible effect of radiometric unbalance among the corresponding portions of the photomosaic. This was verified by examining the pixel gray level values in the individual images for features in overlap areas common to two or more images. The unbalance is not unexpected, of course, since the four input images were acquired on three separate flight lines, one of which occurred in a direction opposite to the other two. Such unbalance, however, will pose a problem when the digital mosaic data are analyzed radiometrically. Therefore, an approximate radiometric matching operation was performed using image GE59 as the reference. Simple transfer functions were derived and applied to match radiometrically the overlap areas of the remaining three images with the reference image. Cumulative distributions of the brightness levels were acquired in the overlap area for two images to be matched. Graphically, the ordinate in these distributions is the percent number of pixels having brightness equal or less than digital level L, and the abscissa is digital level L. For radiometric balancing between two images A and B, a look-up table of L_B versus L_A (transfer function) is prepared such that L_B will produce the same percent value in the distribution for image B as does L_A for image A. The resultant aerial photomosaic is shown in Figure 3.3.3.2.

3.4 Radar Imagery

GE received thirteen digitized frames of airborne SAR radar imagery from USAETL via a magnetic tape. These overlapping frames were acquired over Elizabeth City, NC using two flight lines. The data had been geometrically corrected prior to digitizing and each frame contained 512 scan lines with 512 pixels per line. The ground resolution in the digitized image turned out to be approximately 6 meters.

3.4.1 Imagery Merging

The radar frames were merged by viewing the overlapping areas and identifying piece-wise linear boundaries. All thirteen frames were merged in this manner prior to data manipulation to register the images to the reference image.

3.4.2 Image Rotation and Resampling

The digital mosaic of radar images was simply rotated and resampled to accomplish its registration to the reference image. The rotation angle of 15.6 degrees was determined by acquiring ground control information and using a linear transformation. Finally, the resampling was performed to obtain 2-meter resolution. The linear transformation used to determine the rotation angle also provided the necessary scaling information. A resampling factor of 2.94 was used for the radar imagery.

The resultant radar mosaic image contained an undesirable pattern along columns at regular intervals. This may be due to performing rotation first and resampling later. This order of operations may be accentuating the residual effects of the line shear operation and should be investigated.

3.4.3 Radiometry Matching

The radar imagery also contained radiometric unbalances among frames similar to that described for the aerial photo imagery in section 3.3.3.2. An approximate radiometric matching operation was performed by taking overlapping images acquired in two different flight lines and deriving a simple transfer function. The resultant radar mosaic is shown in Figure 3.4.3.

Figure 3.3.3.2 Mosaic of Four Digitized Aerial Photo Images

Figure 3.4.3 Mosaic of Digitized Radar Images

4. EXTRACTION OF FOREST AND OPEN WATER AREAS FROM THE DATA BASE

4.1 Extraction Procedure Using Derived Texture Image

Themes (binary images) depicting areas of open water and forest are to be derived from the image data in the data base. In this particular case the image data include, in addition to the photomosaic, airborne radar data and three spectral bands of Landsat Thematic Mapper data. These images could be analyzed in various combinations to extract water and forest. However, to extend further a previously developed technique, the decision was made to attempt the extraction of the desired information from the photomosaic (map-sized) image. The approach to be used is a thematic classification based on photographic image gray-level values in combination with a texture version of that image. This procedure was developed in an earlier phase of the present program.

There was some question as to whether the texture image derived from the digital aerial photomosaic would be too "noisy" to use, since the photomosaic is composed of resampled data. Tests using the photomosaic data and the original digitized photo imagery, however, indicated that comparable classification accuracy and quality were achievable for the two cases, particularly after post-classification filtering.

Therefore, appropriate software was written, and a texture image was derived (using a 5-pixel cross operator) from the digital photomosaic in plane #2. The texture image was inserted in plane #1 of the data base. Next, corresponding sections* of the image data in planes #1 and #2 were copied to another disk in the GE DIAL system. There, for each image section, water and forest themes were extracted based on the gray level-texture value procedure referenced previously.

* Classification into water and forest themes was performed separately for each of two sections (4096 pixels x 2340 lines, and 4096 pixels x 1756 lines) because GE DIAL software was available for use with an image the size of the sections chosen, whereas software applicable to the 4096 x 4096 pixel photomosaic image plane was not available.

4.2 Theme Filtering and Contouring

The image sections containing the desired themes were copied to an unused plane in the data base, and the sections merged. A box filtering operation (spatial smoothing operator) was applied to reduce the non-essential minute detail in each of the binary theme images. For the water and forest themes, 5 x 5 and 19 x 19 pixel filters were used, respectively. Where the water and forest themes are adjacent, the filtering results in a small gap between these two themes. This gap is negligible in a 1:50,000 scale image, but a more sophisticated theme filtering operation could be used to remove it completely, if desired. The filtered themes were inserted in still another unused plane in the data base. Each theme, filtered or raw, is assigned a particular bit-plane number within the 8-bit plane. Figure 4.2.1 is a photographic digital recording of the raw water and forest theme image stored in the data base, and Figure 4.2.2 shows the filtered theme image.

To proceed from the theme images in the data base to a form usable for factor overlays, theme outline or contour data must be produced. For this, the theme polygon contouring process, developed in Phase 4 of this program, was employed. The available contouring software is applicable to a 512 x 512 pixel image in the Interactive portion of the GE DIAL system. Therefore, a 512 x 512 pixel window was selected within the overall photomosaic image, and the water and forest themes within this window were moved sequentially from the data base to the Image Memory Unit associated with the GE DIAL Interactive Analysis operations. There, the theme polygon contouring process was initiated, and an SIF tape was produced containing the contours in vector format. In addition, the water and forest theme images in the data base, derived from the full photomosaic, were sub-sampled to 512 x 512 pixel images and similarly moved to the DIAL Interactive System Image Memory Unit. The polygon contouring process was again initiated and the results placed on the SIF tape in vector format. Because of the numerous small polygons resulting from the sampling procedure, however, it was necessary to perform a theme smoothing operation prior to the contouring. The final polygon contours for the water and forest themes for both 512 x 512 pixel images are shown in Figures 4.2.3 through 4.2.6.

Figure 4.2.1 Raw Water and Forest Themes as Stored in the Data Base

Figure 4.2.2 Filtered Water and Forest Themes as Stored in the Data Base

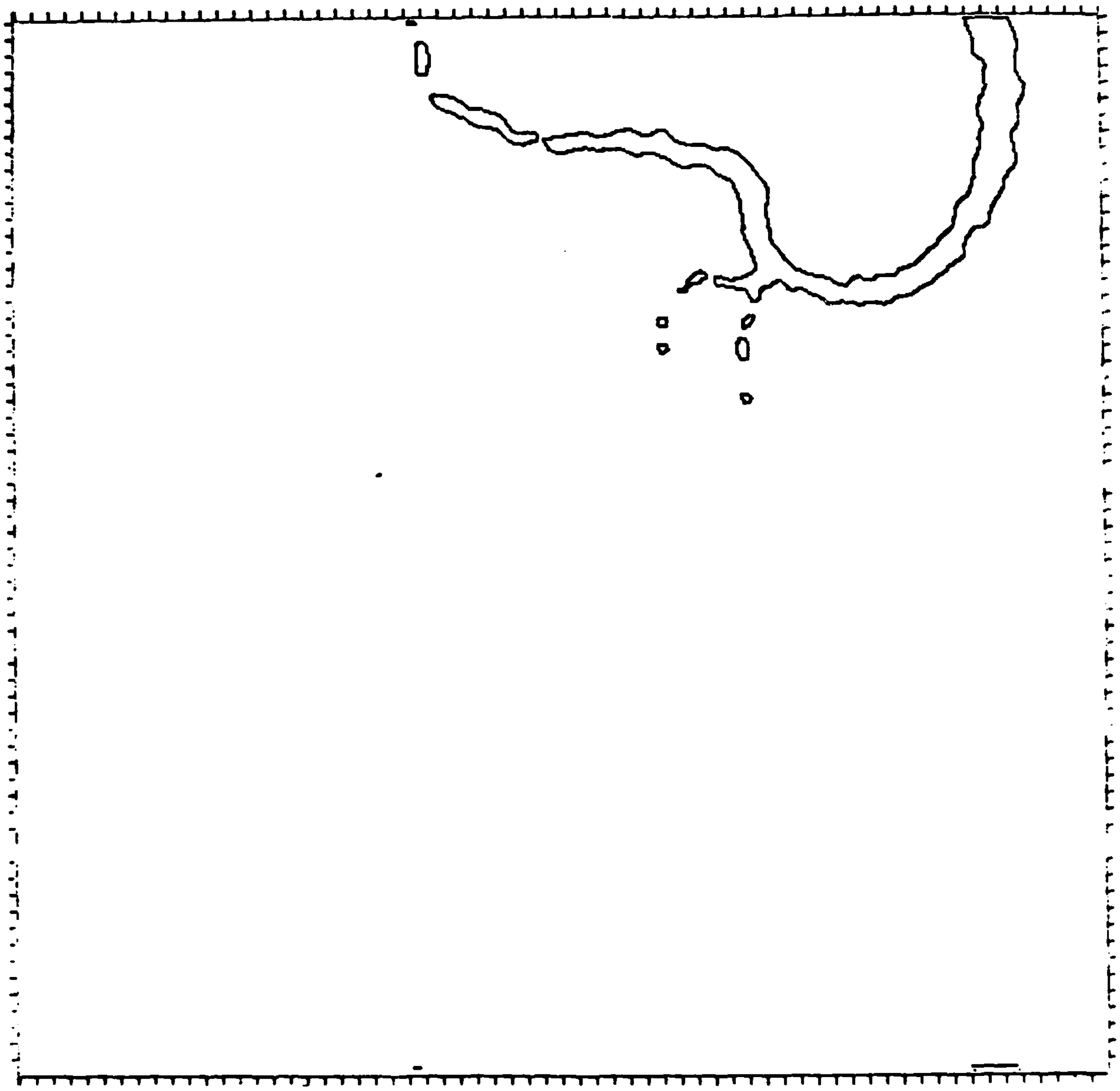


Figure 4.2.3

Water Theme Contours for 512 x 512 - Pixel Window

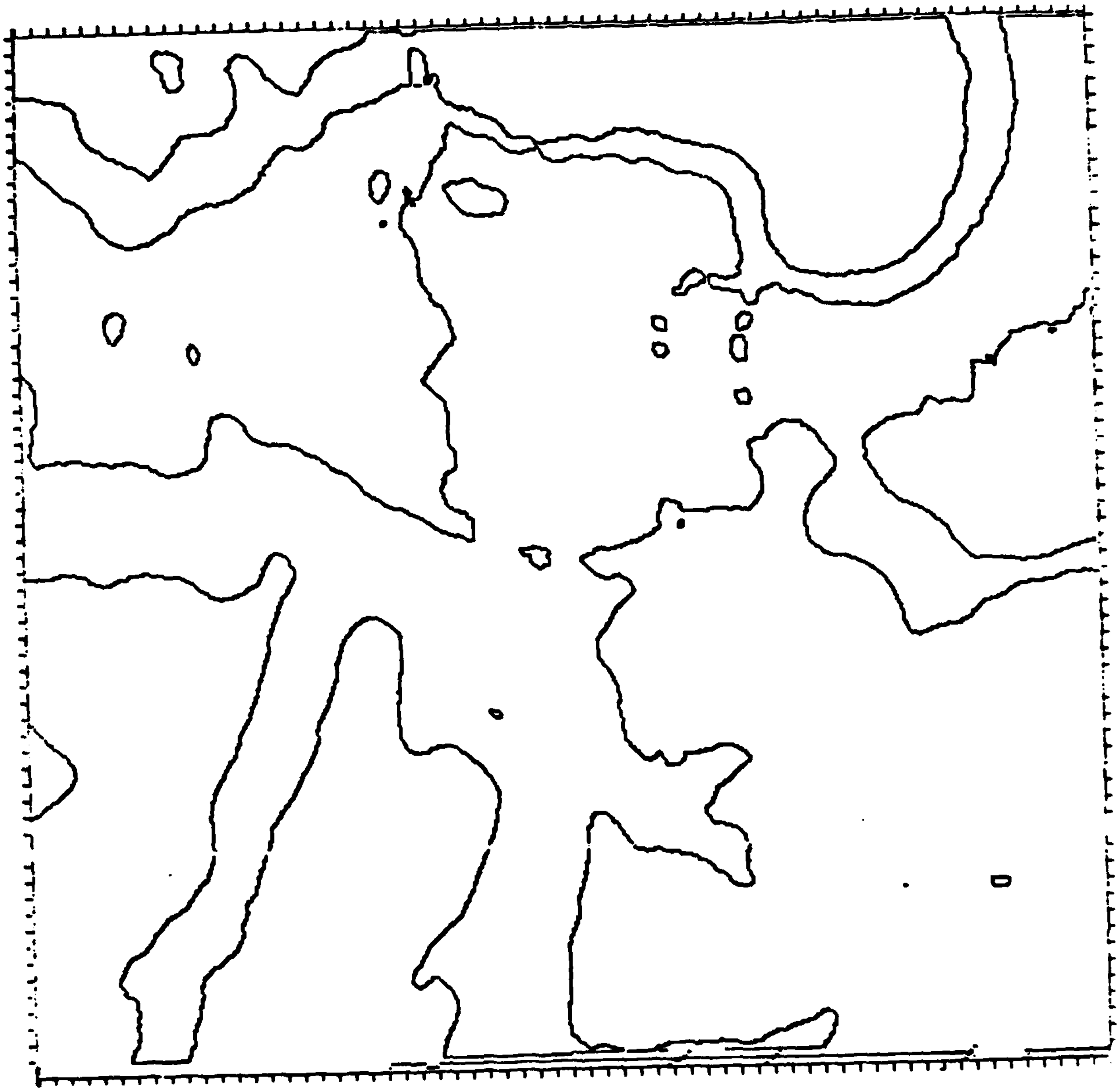


Figure 4.2.4

Forest Theme Contours for 512 x 512 - Pixel Window

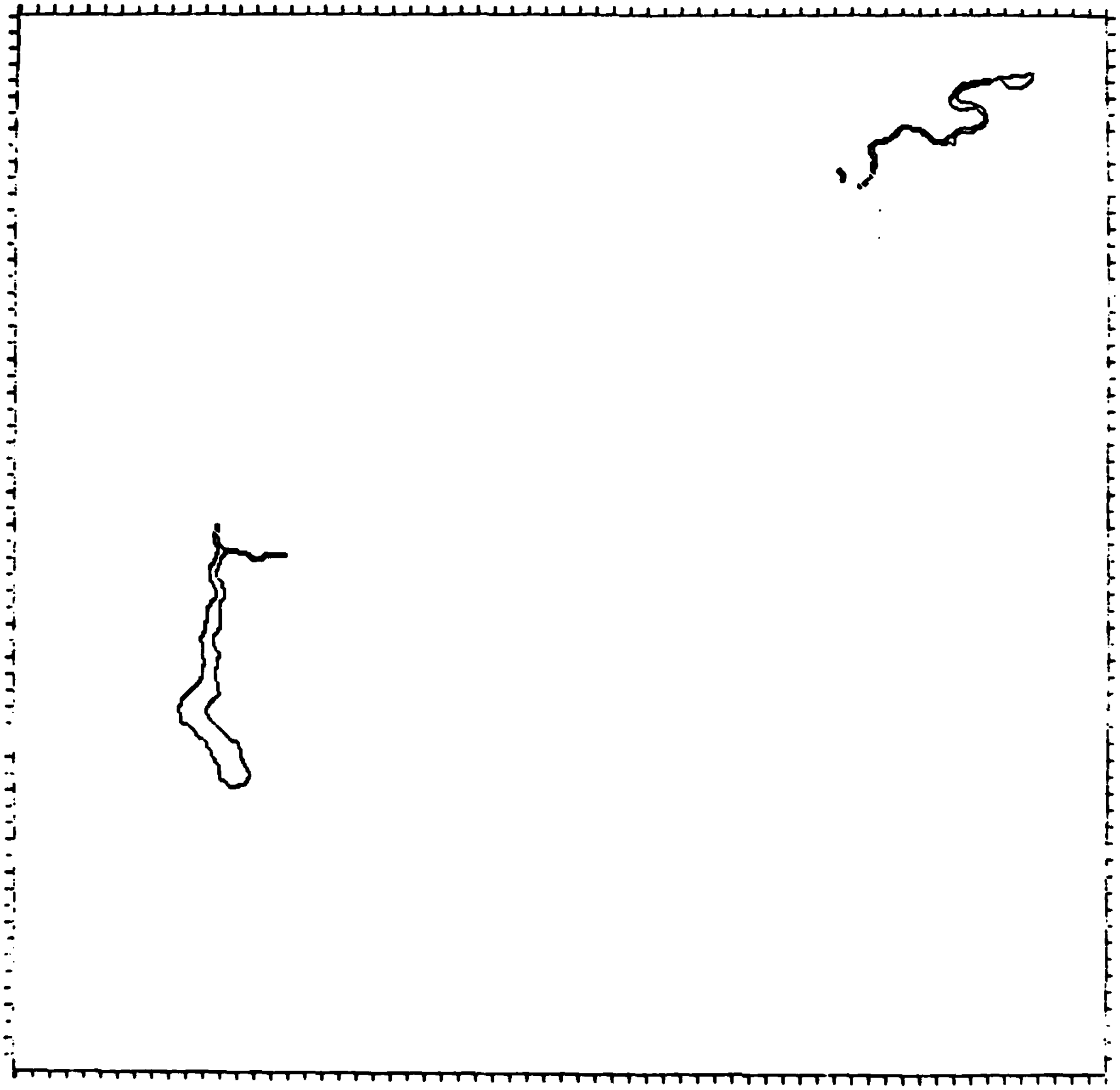


Figure 4.2.5

Theme Contours for Sub-Sampled Data Base Water Theme

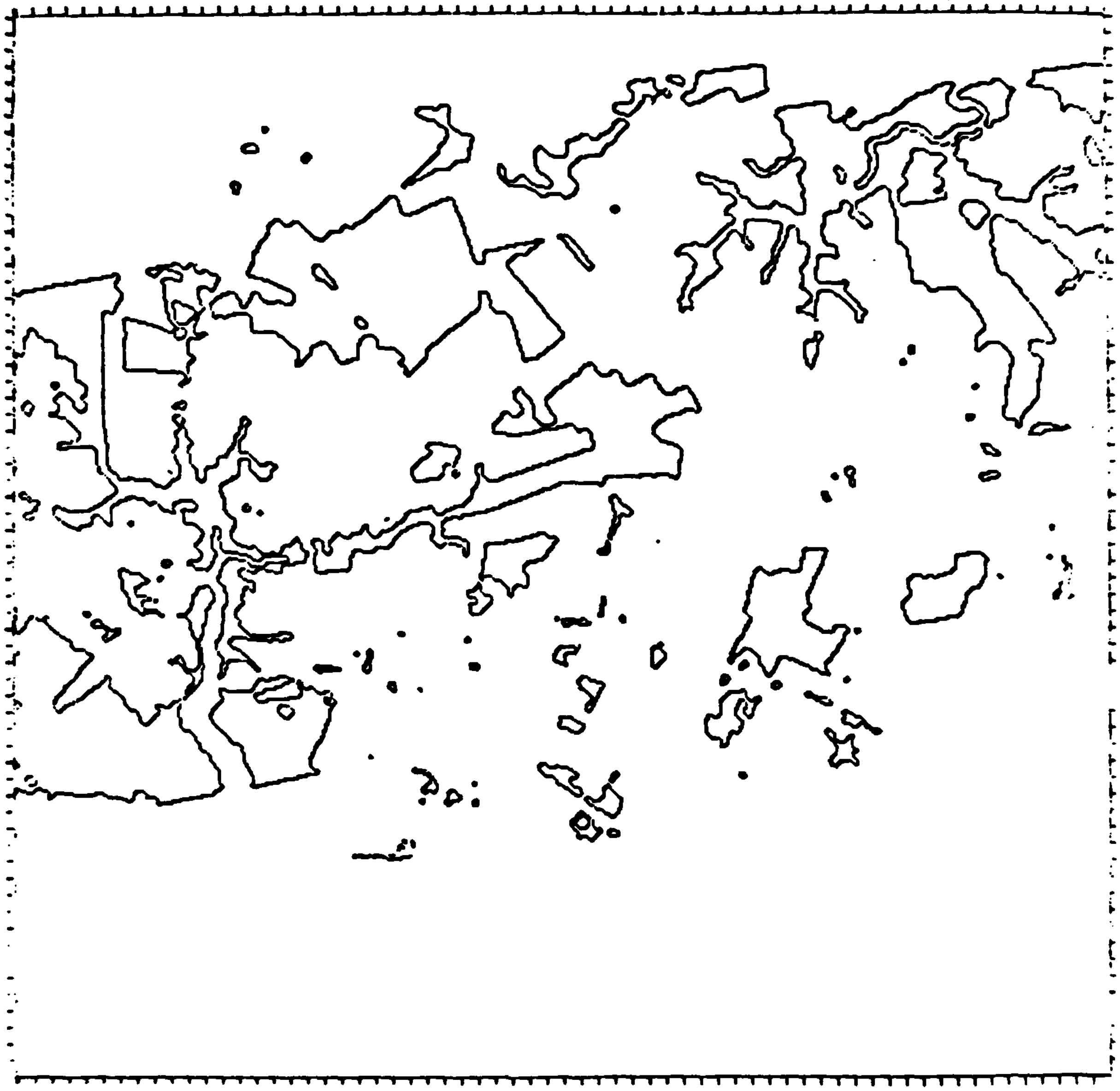


Figure 4.2.6

Theme Contours for Sub-Sampled Data Base Forest Theme

4.3 Description of Final Data Base Images

At the conclusion of the theme extraction task, the image data base contained both original and derived images. These final images and their locations in the 8-bit-per-pixel planes are as follows:

Plane #	Image Description
1	Texture image derived from plane #2 image
2	Digital aerial photomosaic
3	Digital mosaic of airborne radar sub-images
4	Landsat Thematic Mapper Band 2 subscene
5	Landsat Thematic Mapper Band 3 subscene
6	Landsat Thematic Mapper Band 4 subscene
7	Raw classification (all else; Forest; Water)*
8	Intermediate results plane (available)
9	Filtered classification (all else; Forest; Water)*
10	Intermediate results plane (available)

* Bit plane numbers for these themes are, respectively, 1, 2 and 3.

It should be noted that the final assignment of images to data base planes is in a different order from that identified in Figure 2.3.1 which presented the initial conception of the data base. The overall content of the data base, and the number of planes and their size, remain the same, however.

5. CONCLUSIONS

<u>Investigation of Extraction of Surface Configuration Data</u>

a. A useful approach has been demonstrated for extracting the frequency of tonal changes from aerial imagery. The technique should be evaluated on more scenes, however.

b. A technique with some potential has been conceived for the detection of point and linear obstacles using aerial imagery. The technique needs further development, however, and is limited to use with imagery of scenes where there is sun and shadow. A more general technique applicable to clear and overcast conditions is desirable.

c. This investigation of extraction of surface configuration data has been very limited. Not only should the techniques of a. and b. above be investigated further, but techniques should be explored that exploit airborne radar imagery (possibly in combination with other imagery) and digital stereo aerial photography. These additional sources give clues concerning surface topography.

<u>Multi-Plane Image Data Base</u>

d. Landsat Thematic Mapper imagery was used as the reference image in this investigation since there were no maps of the scene available at a scale adequate to locate control points with the required accuracy.

e. The rectification and mosaicking algorithms developed in Phase 4 of this program have been shown to produce satisfactory results with the real-world photo imagery used in this phase (Phase 5). Four aerial photographs were involved, coming from three flight lines with various conditions of tilt.

f. With 28.5M Thematic Mapper resolution, and 2M resolution for a digitized aerial photo, suitable control points could be found common to both images, and with sufficient positional accuracy, to enable photo rectification and registration to the TM reference to within one TM pixel.

g. Radiometric balancing among the photo frames that have been merged into the digital photomosaic is achievable to a degree enabling a single set of thematic classification signatures to be used over the entire photomosaic.

h. There are some vertical artifact lines in the digital radar mosaic that are probably due to the order in which the rotation and resampling operations are performed. Reversing the order should minimize the problem.

i. Using images in the data base having a size of 4096 x 4096 pixels, with 2M per pixel resolution, the data base images cover a scene of 8.2 Km x 8.2 Km. At a scale of 1:50,000, this corresponds to a map size of 0.16M x 0.16M. For a larger (and more realistic) map size with the same pixel resolution, a greater data base capacity is needed.

Terrain Data Extraction from Data Base Imagery

j. Production of binary maps of forest and open water areas, which appear to have good quality and suitable accuracy, is feasible using the digital photomosaic data and its derived texture image. Post-classification theme filtering is necessary, however. The resampling required to produce the photomosaic did not produce classification results significantly different from those using the original digitized photo data.

k. Only the digital photomosaic and its derived texture image have been used in the extraction of information from the image data base. The potential of the radar data and of the multiple spectral bands of the Thematic Mapper data, used singly or in combination with several sources (including the photomosaic), should be explored.

l. In order to exploit the potential of the multiple image sources in the data base to provide terrain information, software for the following purposes needs to be developed:

    1. Pixel-by-pixel thematic classification over the full size of the data base images, drawing on any combination of image sources (planes) in the data base.
    2. Post-classification theme filtering operating over the full size of the data base images.

3. Theme contouring and conversion to vector format, operating over the full size of the data base images.

END

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